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THE EFFECT OF SUBSTITUTING THE DD FORM 250 ACCEPTANCE RATE FOR ACTUAL PRODUCTION RATE WHEN PREDICTING DIREC˜ LABOR REQUIREMENTS FOR MISSILE PRODUCTION PROGRAMS

Giles D. Gentry, Jr., Captain, USAF

LSSR 97-83

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The addition of the production rate variable to the standard learning curve model has been validated as a significant improvement in estimating direct labor hours for airframes, avionics equipment, aircraft engines, and missiles. This research set out to determine if acceptance rate of the end item could serve as a reliable proxy for the production rate variable when production rate data are not available to the researcher. Acceptance rate, as reported on DD Form 250, was substituted for production rate data in a replication of research on the Maverick missile program. Research results failed to support the reliability of the acceptance rate proxy for this program.

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A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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September 1983

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CHAPTER I

INTRODUCTION AND OVERVIEW

> The learning curve has been used extensively in the aircraft industry during the last thirty years to assist in cost estimating for major DOD weapons acquisition programs. Since the introduction of the basic learning curve model, a number of variations have been developed in an attempt to achieve a greater accuracy in predicting actual cost figures [7:6].

The post-World War II years constitute an era of increasing complexity in Department of Defense (DOD) weapon systems acquisitions. Although primary concern has centered on the effective and efficient use of taxpayer dollars, numerous obstacles make this objective difficult to achieve. Tremendous leaps in technology have resulted in weapon systems of previously unimaginable complexity and cost. Further complicating the issue is the need to plan the acquisition and use of these weapon systems over as much as a twenty-year time span with money that is appropriated one year at a time. Even more uncertainty has been added by shocks to the U.S. economy in the form of (1) inflation, (2) increasing cost and questionable availability of energy, and (3) increased competition from foreign countries (2:1).

These conditions contribute to cost overruns in DOD weapons systems acquisitions and clearly illustrate the need for more precise techniques to estimate weapon systems cost. The experience of industry and the DOD indicates that direct labor is a significant determinant of cost. This research will focus on developing a more accurate way to estimate direct labor costs, and, more specifically, the effect of the absence of production rate data on estimating these direct labor costs.

LIMITING THE PROBLEM

At the outset of a major DOD production program, a tentative monthly production schedule for the life of the program is negotiated between the contracting parties. This schedule permits planning for such items as work force build-up, facility and tooling needs, and the ordering of long lead items. Although the planning delivery schedule covers the life of the program, formal contractual agreements between the DOD and manufacturers usually cover only annual delivery requirements. Delivery requirements for subsequent years are funded through the exercise of options or separate contracts as funds are appropriated by the Congress (14:2).

These multiple year programs may result in a need to change the production rate. For example, when funding for a particular year is insufficient to cover the production schedule under an existing production plan, it may be necessary to stretch out the production over a longer time span. A national emergency or changed mission requirement may dictate an accelerated rate of production. When such changes in delivery schedules are required, changes in cost estimates are also required to support contract negotiations and additional funding requests. It is suggested that the rate of production is an important independent variable that can be used to help project the change in unit costs due to either program accelerations or decelerations (14:2). In some instances, however, when actual production rate data are not available, it is not known if a reliable proxy exists to serve for these data.

Industrial and government cost estimators have traditionally used learning curve techniques to estimate direct labor hours required in production (4:25). Learning curve theory is derived from the relationship between the cumulative number of units produced and the number of direct labor hours required for production. In other words, as a worker produces more of a given item, a certain amount of "learning" (proficiency) occurs, and the number of hours required for production tends to decrease in a regular pattern. Learning curve theory is based on the following assumptions:

(1) The production item should be sizeable and complex and should require a large amount of labor.

(2) The majority of assembly operations should not be mechanized or machine-paced.

(3) Learning curves applied from past experience should be adjusted for any differences in items, processes, or other aspects of production.

(4) The production process should be a continuous one and the item and product changes kept to a minimum.

(5) Historical data should be available to compute the curve, since estimated data have low reliability.

(6) There should be no external production rate changes (4:231).

The last assumption is unrealistic for DOD weapon systems acquisition. Changes in production rate are forced on DOD activities quite often. There has been considerable research conducted to correct this apparent limitation of the standard learning curve model (2:4). These studies will be discussed later in this chapter.

One of the most promising studies, by Larry L. Smith, resulted in a model for airframe production which improved the basic learning curve model through the addition of a production rate variable. Smith's methodology has been replicated for aircraft avionics, engines, and missile systems to determine its validity in other types of production. Further replication, using proxies as a substitute for the actual production rate variable is warranted, and forms the basis of this research effort.

STANDARD LEARNING CURVE MODEL

T. P. Wright is generally regarded as the pioneer of learning curve theory. After his initial research, learning curve tables were used at McCook Field, Dayton, Ohio as early as 1925 (5:49-50). Wright's 1936 article on the application of the learning curve to aircraft manufacturing cost estimation is widely regarded as the initial substantive effort in mathematically modeling the learning phenomenon for aircraft manufacturing (16:2D26). As a result of increased aircraft production during World War II, the U.S. Government sponsored a statistical analysis by the Stanford Research Institute on World War II airframe direct labor data. The Stanford study resulted in two important achivements: (1) it confirmed the learning curve effect on World War II production, and (2) it demonstrated the value of a learning curve model for use in cost analysis (16:2D26-27).

> It can be intuitively discerned that for labor production processes which are repetitious, each successive equivalent unit of production will require fewer direct manhours, and that the manhours required decrease at a decreasing rate. This phenomenon, known as the learning or experience curve, has two basic variations. The variation validated by the Stanford study is known as the "unit curve" or the "Boeing theory", and can be expressed mathematically by the formula:
>
> $$Y = AX^b$$
>
> where:
>
> Y represents the direct labor hours for the "xth" unit,

X represents the total number of units manufactured in the process,

A represents the number of labor hours to produce the first unit manufactured in the process, and

b represents the slope parameter or a function of the improvement rate [2:7].

The slope of the curve can be expressed as a percentage, which is the ratio between the per unit cost at any unit and the percent cost at double that number of units [3:199].

The "cumulative average" or "Northrop" variation (described by Wright in his 1936 article) measures the average cost for X units rather than the cost for the xth unit. Its mathematical form is:

$$\bar{Y} = AX^{B}$$

where:

$\bar{Y}$ represents the cumulative average cost of all production up to and including the xth unit.

The other parameters are the same as for the unit curve theory [2:7].

While the Boeing and Northrop models can be manipulated in the same manner, the user should be aware of the difference between the unit cost and the cumulative unit cost measured by these respective models [7:7-9].

As stated above, the basic learning curve model can be manipulated by either unit cost or cumulative unit cost. The unit learning curve (unit cost) of the basic learning curve will be the model used for the remainder of this paper. Also, for purposes of this research, the basic learning curve model will later be referred to as the "reduced model."

Limitations of the Standard Learning Curve Model

Probably due to its simplicity, intuitive appeal, and long history, the basic learning curve model is still widely used. However, the learning curve model does not take into account the exogenous changes in the rate of production. Those exogenous changes are a concern to researchers because of their effect upon the total direct labor requirements.

Concern about exogenous changes in production rate is justified by the following factors: (1) workers will adjust according to pressure to speed up or slow down production; (2) as more workers are employed, the distribution of tasks to each individual worker should narrow; and (3) at higher production rates, tooling costs and set-up costs can be more widely allocated to larger number of units.

Fiscal prudence dictates that each echelon within DOD strive for accurate cost prediction in order to budget, manage, and control. It naturally follows that the importance of production rates in cost estimating must be investigated fully, and that DOD buyers must consider the effects of production rate changes throughout the acquisition process [15:11].

HISTORY OF EFFORTS TO ADD PRODUCTION RATE VARIABLE

The focus of this research involves the addition of the production rate variable, in the form of a proxy, as a second independent variable in the learning curve model. This section will present a chronological history of some of the more important work that has been done in this regard. The list is not exhaustive, and is intended only to provide the reader with a summary of the most widely recognized research efforts in this field. Not all researchers have agreed as to the usefulness of the production rate variable. However, recent efforts show great promise for the production rate to aid in more accurate predictions of labor requirements. If this research effort substantiates the contention that a proxy can be used in place of the production rate variable in the learning curve, DOD researchers will have the opportunity to complete research efforts where the production rate variable is not available.

Harold Asher (1956)

Asher examined the relationship between cost and quantity in the airframe industry. Using empirical data from several airframe production programs, he subjectively evaluated the effect of the production rate on direct labor hour requirements. Asher identified two ways in which the production rate could affect unit labor cost. First, it can affect the amount of machine set-up time charged to each unit of production. Second, it can affect the number of subassemblies in the manufacturing process, which, in turn, affects the number of hours of subassembly work charged to each unit. He concluded that production rate was not very important as a predictor when compared to the effect of cumulative production (3:86-87).

Alchian and Allen (1964)

Alchian and Allen advanced the idea that production cost is dependent on three production variables: (1) total volume of the item to be produced, (2) production rate, and (3) amount of time from the decision to produce until the first output occurs (14:19). They drew three major conclusions. First, larger total volumes lead to smaller unit costs because of increased product standardization that accompanies larger volume. Second, unit costs increase with increasing production rates because more overtime and less efficient workers are needed to support the increased production rate. Third, the cost variable increases if the initial production start-up time is compressed. They explained that less efficient procedures are used than if time were allowed to prepare properly for production. Subsequent effort expended to correct these inefficiencies results in higher unit costs (1:308-322).

Although Alchian and Allen did not test their conclusions on actual data, their ideas may have application to the airframe industry (14:20).

Gordon J. Johnson (1969)

Johnson predicted labor requirements for rocket motors using an additive model which considered both the rate effect and the learning effect. The model he used was:

$$y = A + BX_1 + CX_2^Z$$

where:

y represents direct labor hours per month,

X_1 represents production rate in equivalent units per month,

X_2 represents cumulative units produced as of the end of the month, and

A, B, C and Z are model parameters.

Johnson regressed this model against four sets of rocket motor data. His results are shown in Table I. As depicted in the table, Johnson had good results (high R^2) with data sets 1 and 4, fair results with data set 2 and poor results with data set 3. Johnson explained data set 3's poor results as being due to an inadequate accounting system used by the manufacturer. He concluded that the production rate is a significant determinant of direct labor requirements [7:10].

Joseph A. Orsini (1970)

Orsini (12:57-80) tested Johnson's rocket motor model using airframe data from the C-141 program. He employed the following procedure: (1) regression analysis was performed on the data using the standard unit learning curve model, (2) regression analysis was again performed using Johnson's three dimensional additive model that incorporated rate of production, and (3) analysis was performed after converting Johnson's additive model into a multiplicative one which is stated as follows:

$$Y = e^{B_0} \cdot X_1^{B_1} \cdot X_2^{B_2}$$

where:

Y represents the direct labor hours per quarter,

X_1 represents the number of units produced per quarter,

X_2 represents the cumulative number of units produced as of the end of the quarter,

TABLE 1

SUMMARY OF JOHNSON'S REGRESSION ANALYSIS

Regression Variables	Coefficients of Determination (R^2)			
	Data Set			
	1	2	3	4
Labor Hours vs. Cumulative Units	.753	.395	.0067	.763
Labor Hours vs. Cumulative Units and Production Rate	.932	.808	.308	.927

Source: [9:34].

B_0, B_1, and B_2 are model parameters and e is the base of the natural logarithms [2:11-12].

Orsini concluded that (1) inclusion of the production rate as an independent variable significantly improved the predictive ability of both the additive and multiplicative models, and (2) the multiplicative model performed better as a predictor than did the additive one because it eliminated the need to estimate the parameter Z (12:71).

Large, Hoffmayer, and Kontrovich (1974)

During an effort to develop a general model, Large, Hoffmayer, and Kontrovich examined data from major airframe acquisitions relating to the effect of production rate on cost. The model used, according to Smith (14:29-30), is of the form:

$$Yi = A \cdot w^B \cdot s^C \cdot r^D$$

where:

Yi represents the cumulative direct manufacturing labor hours through unit number i,

w represents the program average Defense Contractor Planning Report (DCPR) weight expressed in pounds,

s represents the maximum design airspeed in knots,

r represents the production rate expressed as the acceptance span in months for the first i airframes.

(For their investigation, Large, Hoffmayer, and Kontrovich chose i arbitrarily to be 100 or 200), and

A, B, C and D are model parameters [2:12].

Large, Hoffmayer, and Kontrovich concluded that the effects of the production rate could not be predicted with confidence, especially in the early stages of a major acquisition. They concluded that each case must be considered separately (10:50-51). Smith (14:31) indicated that the use of an acceptance span as a proxy for production rate masked the true effect of the production rate because of the resultant averaging effect.

Joseph Noah

Noah analyzed cost data to find the effect of production rate on airframe costs. His model for the data was:

$$y = e^{A} \cdot X_1^{B} \cdot X_2^{C} \cdot X_3^{D}$$

where:

y represents average direct labor hours per pound of airframe for each airframe lot,

e is the base of the natural logarithm,

X_1 represents the cumulative volume in pounds of aircraft produced by the midpoint of each airframe lot,

X_2 represents the production rate in average pounds of airframe delivered per month for the entire period,

X_3 represents the annual volume of aircraft in airframe pounds, and

A, B, C, and D are model parameters.

Noah averaged the estimated regression coefficients from two sets of data, one on the F-4 and the other on the A-7, and tried to develop a generalized cost model. Smith felt that this approach was questionable and that the model needed to be tested on additional aircraft programs to determine if it did actually serve as an accurate predictor. Also, Smith stated that while the lot average airframe delivery rate was a practical representation of the production rate, the average delivery rate variable appeared to lag the average expenditure of hours required to produce the airframes delivered [7:10,12].

Larry L. Smith (1976)

Smith developed a model for airframe production that included a production rate variable to test the idea that production rate changes can explain changes in direct labor requirements (14:35). He adapted a modified version of Orsini's multiplicative model as follows:

$$Y_i = B_o \cdot X_{1i}^{B_1} \cdot X_{2i}^{B_2} \cdot 10^{e_i}$$

where:

Y_i represents the unit average direct hours needed to output each pound of airframe in lot i,

X_{1i} represents the cumulative learning accrued from experience on all airframes of the same type through lot i,

X_{2i} represents the production rate of lot i for all airframes of the same type,

e_i represents the variation of each dependent variable which is not explained by the two independent variables,

B_o, B_1, and B_2 are parameters in the model [14:43].

Smith also linearized the model to facilitate multiple linear regression. The linearized form was:

$$\text{Log } Y_i = \text{Log } B_o + B_1 \text{ Log } X_{1i} + B_2 \text{ Log } X_{2i} + ei \text{ (14:45)}.$$

To test the accuracy of his model versus the standard learning curve model, Smith employed a "reduced" model which was merely his model, or "full" model, minus the production rate variable. The "reduced" model was a unit learning curve model as follows:

$$Y_i = B_o \cdot X_{1i}^{B_1} \cdot 10^{e_i} \text{ (13:43)}.$$

Regression of historical data with each model allowed Smith to identify the contribution of predictive ability by the production rate variable (15:17-18).

Evaluating data from the F-4, F-102, and KC-135 airframe production programs, Smith reached the following conclusions: (1) in each case, the production rate variable was negatively correlated with unit direct labor requirements, (2) both proxies to the production rate variable were important contributors to the full model's predictive ability, and (3) as evidenced by the R^2 values he obtained, the full model more closely fit the data than the reduced model (14:142-146). Tables 2 and 3 summarize Smith's regression analysis and predictive ability test results.

Congleton and Kinton (1977)

Using the same methodology, Congleton and Kinton replicated Smith's research for the T-38 and F-5 airframe production programs. They reached the same basic conclusions as Smith; however, in one of the thirty test situations they reported that R^2 was higher for the reduced model than for the full model, but by less than one percent (6:91-93).

Stevens and Thomerson (1979)

Stevens and Thomerson replicated Smith's model for aircraft avionics systems. Specifically, they examined the Magnavox ARC-164 radio, applying the methodology set forth by Smith. Stevens and Thomerson formed the following conclusions: (1) production rate was a significant factor in explaining variations in direct labor hours in nine out of ten cases, (2) the predictive ability of the full model was better than that of the reduced model for eighteen months into the future, (3) the standard learning curve (reduced) model consistently overestimated direct labor hours while the full model stabilized predictions over an extended interval, (4) regression coefficients are unique to the program for which they are derived, and (5) the overall applicability of Smith's model has wide potential and can be tailored to various other programs (15:102-104).

Crozier and McGann (1979)

Crozier and McGann also replicated Smith's research. They applied both the reduced model (standard learning

TABLE 2

SUMMARY OF SMITH'S REGRESSION ANALYSIS†

Test Situation Number	Data Points	R_f^2 (actual)	R_r^2 (actual)	B_o	B_1	B_2
1	57	0.978	0.928	masked*	-0.261	-0.169
2	55	0.973	0.904	"	-0.246	-0.183
3	55	0.966	0.904	"	-0.257	-0.161
4	42	0.853	0.585	"	-0.230	-0.157
5	42	0.820	0.585	"	-0.229	-0.136
6	42	0.889	0.618	6.328	-0.221	-0.148
7	42	0.851	0.618	7.601	-0.219	-0.127
8	42	0.744	0.658	9.016	-0.279	-0.112
9	42	0.733	0.658	10.400	-0.278	-0.097
10	50	0.979	0.961	38.371	-0.299	-0.158
11	42	0.979	0.959	47.290	-0.344	-0.144
12	96	0.958	0.971	13.133	-0.453	-0.164
13§	7	0.974	0.903	0.674	-0.165	-0.305
14§	7	0.971	0.903	1.123	-0.233	-0.222
15§	7	0.994	0.964	13.338	-0.608	-0.361
16§	7	0.992	0.964	7.303	-0.527	-0.262

*The total production hours per pound were considered proprietary by the manufacturer, and these coefficients were masked in the published version of Smith's research (15:65).

†Smith's methodology, production rate proxies, and R^2 versus R^2 (actual) are all recapped in Chapters II and III of this research. The subscripts for R^2 are as follows: f stands for full model; r for the reduced.

§Impractical for test situations.

Source: [2:16].

TABLE 3

SUMMARY OF SMITH'S PREDICTIVE ABILITY TEST RESULTS

Test Situation Number	Percentage Deviation*	
	Full Model	Reduced Model
1	-2.6	14.5
2	2.2	13.6
3	Not Reported	13.6
4	1.8	5.3
5	3.1	5.3
6	-7.8	Not Reported
7	†	Not Reported
8	-0.7	1.1
9	-4.2	1.1
10	-1.1	5.6
11	3.5	Not Reported
12	2.2	-3.3
13-16	§	§

*These tests were conducted as described in Chapter II of this research. All percentages are rounded to nearest tenth.

†Smith reported the results were deviations greater than those for test situation 6, but did not report a value (14:96).

§Smith reported that predictive ability tests were impractical for situations 13 through 16 because observations were limited to seven (14:71-131).

Source: [2:16].

curve) and the full model to three aircraft engine programs: (1) the General Electric J-79, (2) the Allison TF-41, and (3) the Pratt and Whitney F-100. They found that the production rate significantly explained variation in direct labor hours in three of the six cases examined, with especially good results on the F-100 engine. On engine programs, the full model was a better predictor than the reduced model. Crozier and McGann concluded that the results when using Smith's model depend a great deal on the type of weapons system. This last finding justifies the need for more replication efforts of Smith's model (7:92-94).

Allen and Farr (1980)

The findings of Allen/Farr are crucially important to this research effort. They replicated Smith's model for the Maverick and SRAM missile programs, utilizing twelve models in their research methodology. Smith's model was replicated for the fabrication, assembly, and test components of the two missile programs and Allen/Farr concluded that the production rate was found to explain a significant amount of variation in direct labor hours in nine of the twelve models examined. Enough support was evident to conclude that the production rate variable should be considered when evaluating missile production programs. Whereas Allen/Farr used the production rate as the second independent variable in the full model, this research will use their data and substitute a proxy for the production rate variable. This substitution will test the reliability of the proxy as a substitute when production rate data are not available. The details of this proxy and its application to the model are discussed later in this paper.

RESEARCH PROBLEM STATEMENT

Past research efforts have shown that changes in production rate affect direct labor hours for continuing weapon systems production programs. These past research efforts used the number of end items completed during an accounting month as their measure of production rate. This measurement of production rate is not always accessible for the following reasons: (1) the contractor may be unwilling to furnish the data, or (2) the contractor may not collect the data in a format suitable for use in learning curve analysis. Whenever the actual production rate data is not available, a proxy must be employed in its place. One easily accessible proxy for actual production rate is the DD Form 250 acceptance rate. This form is always used in DOD weapon system production programs to document end item acceptance and is readily available to DOD researchers. The use of a proxy, such as the DD Form 250 acceptance rate, in lieu of actual production rate data in predicting direct labor hours for continuing weapon system production programs is not known.

RESEARCH OBJECTIVE

The objective of this research is to determine if the DD Form 250 acceptance rate can be substituted for the actual production rate variable contained in Smith's model without compromising the predictive ability of that model.

RESEARCH HYPOTHESIS

The predictive ability of Smith's model is not compromised by the substitution of the DD Form 250 acceptance rate for the actual production rate variable.

PLAN OF DEVELOPMENT

With the problem narrowed and the objective outlined, the next chapter is devoted to a discussion of the methodology for testing the research hypothesis. A brief summary of assumptions and limitations about the methodology will close Chapter II. Chapter III will contain the data analysis and evaluation. Finally, Chapter IV will contain the summary, conclusions, and recommendations of this research.

CHAPTER II

RESEARCH METHODOLOGY

This chapter outlines the procedures used to test the research hypothesis. The chapter is divided into five sections as follows:

(1) Restatement of Objective,

(2) Model Definition, Variables, and Assumptions,

(3) Data Collection,

(4) Analysis Methodology, and

(5) Summary.

RESTATEMENT OF OBJECTIVE

The objective of this research is to determine if the DD Form 250 acceptance rate can be substituted for the actual production rate variable contained in Smith's model without compromising the predictive ability of that model.

MODEL DEFINITION, VARIABLES, AND ASSUMPTIONS

Model Definition

Chapter I discussed the two models used by Smith, which he called the "full model" and the "reduced model." For ease of reference, the two models are repeated.

The reduced model is the basic learning curve stated as:

$$Y_i = B_o \cdot X_{1i}^{B_1} \cdot 10^{e_i} \quad .$$

In the full model, the production rate variable is added as follows:

$$Y_i = B_o \cdot X_{1i}^{B_1} \cdot X_{2i}^{B_2} \cdot 10^{e_i} \quad .$$

Model Variables

The three variables used in this analysis were: (1) direct labor hours per missile produced, (2) cumulative number of missiles produced, and (3) the DD Form 250 acceptance rate as a proxy for the missile production rate. Since it was considered desirable to improve the ability to predict the direct labor hours required per missile, direct labor was treated as the dependent variable. Cumulative missiles produced and the acceptance rate were considered the independent variables.

The Direct Labor Hours Variable. Direct labor is usually measured in hours, although it is occasionally measured in dollars. Whenever the data are expressed in dollars, care must be taken to accurately account for inflation. The primary determinants of total direct labor are (1) fabrication labor, (2) assembly labor, and (3) test labor. Depending on the individual contractor, the data may be expressed as total labor or any combination of the component parts (fabrication, assembly, and test). The exact measure of the data is unimportant as long as a consistent unit of measurement is maintained (2:21). This research will measure total direct labor in hours. Referring again to the reduced and full models, direct labor is depicted by the variable Y_i. Y_i represents direct labor hours required for each missile, where:

Y_t = total direct labor hours per accounting month,

Y_{tu} = unit index portion of total direct labor hours per accounting month,

Y_{tsh} = standard hours portion of total direct labor hours per accounting month,

Y_f = fabrication direct labor hours per accounting month,

Y_{fu} = unit index portion of fabrication direct labor hours per accounting month, and

Y_{fsh} = standard hours portion of fabrication direct labor hours per accounting month.

The Cumulative Output Variable. Records are normally kept for the number of missiles completed each month. The cumulative output is the total number of missiles completed since the beginning of the production program as of the end of a specific accounting month (2:22). The cumulative output variable is depicted by the variable X_{1i} and represents the cumulative output of all missiles through the i^{th}.

The Acceptance Rate Variable. The production rate is the number of missiles completed during an accounting month. For some production processes, the production rate is difficult to accurately assess. Whenever this situation occurs, a proxy must be developed for the production rate.

Commonly used proxies are the delivery rate and the acceptance rate (2:22). The production rate variable used in this research effort will be the missile acceptance rate, earlier referred to as the DD Form 250 acceptance rate. The acceptance rate is depicted by the variable X_{2i} and represents the acceptance rate of the missiles in group i.

Miscellaneous Variables. e^i represents the variation which is left unexplained by the variables in the model and B_o, B_1, and B_2 are the regression coefficients for the model.

In order to use multiple linear regression to analyze the two models, they were transformed to a linear form by taking the logarithm of each term. The logarithmic form of the reduced model is:

$$\text{Log } Y_i = \text{Log } B_o + B_1 \text{ Log } X_{1i} + e_i \quad .$$

The logarithmic form of the full model is:

$$\text{Log } Y_i = \text{Log } B_o + B_1 \text{ Log } X_{1i} + B_2 \text{ Log } X_{2i} + e_i \quad .$$

Assumptions

The statistical significance of the results of the regression will be tested using appropriate F-distribution statistics. To establish the validity of these tests, it is necessary to make some assumptions concerning the error terms in the model. First, the error terms are assumed to be normally distributed with a mean of zero and equal variance. Second, the error terms are assumed to be independent of each other and of the independent variables (11:30-31).

A third assumption concerns a problem which frequently develops in multiple linear regression, that of multicollinearity. Multicollinearity exists when there is a high correlation between or among independent variables, which in this research are cumulative output and acceptance rate. If a strong correlation exists between or among independent variables, the F-test may find the marginal contribution of one or more variables to be statistically insignificant when, in fact, they may be good explainers of variation in the dependent variable if considered separately (11:341).

While multicollinearity can be a serious problem if the model is to be used for control, it is not as serious a problem when the purpose of the model is to predict, as is the case in this research (11:342). The contribution made by adding the acceptance rate to the reduced model will be subjectively evaluated by comparing predictions of the reduced model to those of the full model. Therefore, it is assumed the varying degrees of multicollinearity will have no substantial impact on the short-range predictive abilities of the models (2:24).

DATA COLLECTION

As in all previous research using Smith's model, accessibility of data is a very important determinant in selecting the particular program to be studied. The data must be the actual historical data rather than estimates. The data represents a census rather than a sample and statistics derived for each individual population are, therefore, descriptive of only that population. Consequently, the information derived is applicable only to the program being studied in this research. The regression coefficients found in this research must not be indiscriminately applied to other missile production programs.

The data furnished by the Hughes Aircraft company consisted of total direct labor requirements and production history for the total Maverick missile production. Full-scale production commenced April 1972 and continued without interruption through May 1978 (73 months), resulting in the manufacture of 26,500 units. During the 73 months of production, the government accepted 68 deliveries using the DD Form 250.

This research effort uses the same data as used by the Allen/Farr team in their research except for production rate. Where Allen/Farr used actual production rate, this research uses the DD Form 250 acceptance rate as a proxy for actual production rate. Because the data reflected significant fluctuation in the acceptance rate, the Maverick program provides an excellent test situation for this comparative research. In the Allen/Farr research, the Maverick data were broken down into several major components: fabrication, assembly, and test. These three components were then incorporated into a total model. This research models only the fabrication component and the total model used in the Allen/Farr effort. Funding limitation precluded incorporating the assembly and test components into this research.

One intriguing aspect of the Maverick data was the manner in which the manufacturer accounted for direct labor hours. Direct labor hours were segmented into two components: Unit Index and Standard Hours. On a continuing basis, Hughes conducted time and motion studies to estimate how many hours it would take to manufacture each missile under "ideal" conditions at a particular point in the production program. This estimate was called Standard Hours, and its evolution over time represented a measure of methods improvement. For each month of production, Hughes computed a Unit Index reflecting the deviation between actual number of direct labor hours required for production and the number of hours that would be required under ideal conditions. Whenever the actual number of hours required for production achieved the "ideal" standard, the Unit Index was equal to one. Any value of the index greater than one reflected less than ideal performance. The evolution of the index over time represented a measure of labor improvement or learning. To calculate direct labor hours per missile, the Unit Index was multiplied by the Standard Hours. For example, assume the program is in the early stages of production, the Standard Hours are 100 hours per unit and the Unit Index is 2.50 per unit (less than perfect conditions). The two are then multiplied to calculate total hours per missile of 250.

As one might expect, the Unit Index, Standard Hours, and direct labor hours exhibited learning trends to varying degrees. Because of this unique accounting procedure, Allen and Farr were able to assess the effects of the production rate on both the "labor learning" and "methods improvement" aspects of direct labor (2:39). The same advantage holds for this research because of the simplicity of substituting the acceptance rate proxy for actual production rate.

The raw data are transformed into logarithmic form to be used in six different models for this research. The first three models are labeled as follows:

Model One: Total Hours Per Unit,

Model Two: Unit Index for Total Hours Per Unit, and

Model Three: Standard Hours for Total Hours Per Unit.

The last three models are labeled as follows:

Model Four: Fabrication Hours Per Unit,

Model Five: Unit Index for Fabrication Hours Per Unit, and

Model Six: Standard Hours for Fabrication Hours Per Unit.

Regression analysis is performed on both the reduced and the full forms of the models, and test statistics are calculated. The test statistics are then compared with the critical values required, and the criterion tests are applied to determine if the model is acceptable for testing. If the results for a particular model support its acceptability and the criterion tests fail to reject the model as inappropriate, that model is then tested for its predictive ability. The statistical tests, criterion tests, and their objectives for this research effort are discussed in detail in the following section.

ANALYSIS METHODOLOGY

The hypothesis to be tested in this research is that the predictive ability of Smith's model is not compromised by the substitution of the DD Form 250 acceptance rate for the actual production rate variable.

Testing this hypothesis first requires determining if the model, using the DD Form 250 acceptance data, is acceptable. Then, if the model is found to be acceptable, the predictive ability of the model is compared to the predictive ability of the model using actual production rate data to determine if any compromise exists.

To determine if a model using the DD Form 250 acceptance rate is acceptable requires two steps. The first step examines the statistical significance of the model's regression coefficients by regression analysis of historical production data. This step is composed of two statistical steps. The second step involves the use of two criterion tests to evaluate the *appropriateness of* the model for this data. The dependent variable of the full model, in log-linear form, will be subjected to regression analysis. The independent variables are the logarithms of cumulative output and the DD Form 250 acceptance rate.

MODEL ACCEPTABILITY TESTING

Statistical Tests

The first statistical test (ST1) examines the relationship between the cumulative output and acceptance rate variables and the direct labor hour variable as shown in the model. The null hypothesis and its alternate are formed as follows:

H_0: B_1 and $B_2 = 0$

H_A: $B_1 \neq 0$ and/or $B_2 \neq 0$.

This hypothesis will be tested using the following format:

(1) State the null and alternate hypothesis.

(2) State the alpha level (level of significance).

(3) State the test statistic. The test statistic for statistical test one will be the F-test.

(4) State the Decision Rule. If the F-ratio is greater than F*, reject H_0, else cannot reject H_0.

(5) State the Decision based upon the Decision Rule.

Mathematically, F-ratio = MSR/MSE, MSR = SSR/p-1, and MSE = SSE/n-p where:

MSR represents the mean of the regression sum of squares in logarithmic form,

MSE represents the mean of the error (or residual) sum of squares in logarithmic form,

SSR represents the regression sum of squares in logarithmic form,

SSE represents the error (or residual) sum of squares in logarithmic form,

n represents the number of observations, and

p represents the number of parameters in the model (11:45, 79, 227-228).

The F-ratio compares the explained variance (MSR) to the unexplained variance (MSE), and thus determines the ability of the model to explain the variance of the dependent variable (2:26).

The second statistical test (ST2) tests the ability of the DD Form 250 acceptance rate variable, when combined with the cumulative output variable, to explain additional variation in direct labor hours per missile. Statistically, the null and its alternate hypotheses are:

H_O: $B_2 = 0$

H_A: $B_2 \neq 0$.

This hypothesis will be tested using the following format:

(1) State the null and alternate hypotheses.

(2) State the alpha level (level of significance).

(3) State the test statistic. The test statistic for statistical test two will be the F-test.

(4) State the Decision Rule. If the F-statistic is greater than F*, reject H_O, else cannot reject H_O.

(5) State the Decision based upon the Decision Rule.

The value of F* is determined as follows:

$$F^* = \frac{\Delta R^2/g}{(1-R^2)/(n-k-1)}$$

where:

ΔR^2 represents the increase in explained variations caused by the addition of the logarithm of the acceptance rate variable to the reduced model,

g represents the number of variables (in this case, one) which cause the increase in R^2,

n represents the number of observations,

k represents the total number of regressors, and n-k-l represents the degrees of freedom in the unexplained variation (17:435).

The F* statistic in this test yields a ratio of the increase in explained variance to the remaining unexplained variance which resulted from introducing the acceptance rate variable into the reduced model (2:27).

Criterion Tests

The first criterion test (CT1) for the appropriateness of the model concerns the assumptions about the residuals, or observed errors. The model is considered appropriate for the data if the assumptions about constant variance of residuals, independence of residuals, and normal distribution of residuals cannot be rejected on the basis of appropriate tests (11:240).

The assumption of constant variance of residuals is tested by plotting the residual values against the predicted values of the dependent variable. The assumption is accepted if the plot revealed an even distribution (no discernible pattern) and if most residuals are within one standard error of the estimate (11:239-240).

The Durbin-Watson Test (2:28) was used to check for independence of residuals. The test determined whether or not the autocorrelation parameter ρ was equal to zero. The test alternatives were:

H_O: $\rho > 0$

H_A: $\rho = 0$.

This portion of criterion test one (CT1) will be tested using the following format:

(1) State the null and alternate hypotheses.

(2) State the alpha level (level of significance).

(3) State the test statistic. The test statistic for criterion test one will be the Durbin-Watson statistic.

(4) State the Decision Rule. If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive.

(5) State the Decision based upon the Decision Rule.

A statistical package called "STAT II" in the Copper Impact Library at the Air Force Institute of Technology calculated the Durbin-Watson statistic designated as D. Table A-6 in the Neter and Wasserman text contained upper and lower bounds (d_U and d_L) for various sample sizes, levels of significance, and numbers of independent variables. The calculated D statistic was compared to the upper and lower bounds in the table at the 0.05 level of significance. If H_A was concluded, the residuals were considered to be independent (2:29).

The assumption of normal distribution of residuals was tested through the Kilmogorov-Smirnov (KS) test. The basis of the KS estimation procedure is the cumulative sample function, which is denoted by S(X). S(X) specifies for each value of X the proportion of values less than or equal to X. The KS procedure utilizes a statistic, denoted by D(n), which is based on the differences between the cumulative sample function S(X) and the true cumulative probability function F(X).

$$D(n) = \text{Max } |S(X) - F(X)| \ .$$

In other words, D(n) equals the largest absolute deviation of S(X) from F(X) at any value of X. D(n) is shown as a function of n because it depends on the sample size. Surprisingly, however, it does not depend on the specific form of F(X). Hence, the KS procedure may be used for goodness of fit tests for any shape distribution, and will be used in this case to see if the residuals were normally distributed (2:29).

The KS statistic used in this research was calculated by the STAT II package in the Copper Impact Library. If the calculated statistic was below the critical value in the D(n) table, the data were considered normal. Stated in hypothesis form:

H_O: $KS \geq D(n)_c$

H_A: $KS < D(n)_c$.

This portion of criterion test one (CT1) will be tested using the following format:

(1) State the null and alternate hypotheses.

(2) State the alpha level (level of significance).

(3) State the test statistic. The test statistic for this portion of CT1 is the KS test.

(4) State the Decision Rule. If KS is less than $D(n)_c$, reject H_O.

(5) State the Decision based upon the Decision Rule.

The second criterion test (CT2), which also tests the appropriateness of the model, involves the use of the multiple coefficient of determination, known as R^2. The R^2 value measures the proportion of variation in direct labor hours that is explained by the regression model. R^2 is calculated by subtracting the quotient of SSE/SSTO from one. The error sume of squares, SSE, is the summation of all squared residuals, and is formally defined in statistical test one (ST1). The total sum of squares, SSTO, is calculated by summing the squared differences between each observed value of the mean of the dependent variable (11:77).

In this model, R^2, as a valid measure of explained variation, is somewhat obscured by the transformation of the model to logarithmic form. R^2 in that form represents the logarithmic value of direct labor hour variation rather than variation in actual hours. Smith, in his research, developed a more meaningful statistic which he called R^2 (actual) (14:53). R^2 (actual) is calculated in the same way that R^2 is, except that the SSE and SSTO values are calculated after transforming the observed and predicted values of the dependent variables from the logarithmic to actual form. In that way, the variation is represented in actual hours instead of logarithms (2:31).

An appropriate model for the data would explain a high proportion of variation in direct labor, and would consequently yield a high R^2 (actual). Therefore, in this criterion test, an R^2 (actual) value of .75 or higher is selected as the level at which the model could not be rejected as inappropriate (2:31).

If an acceptable model is found after model acceptability testing (ST1, ST2, CT1, and CT2), predictive ability is then tested.

PREDICTIVE ABILITY TESTING

After the full model, with DD Form 250 data incorporated, is accepted as the result of model acceptability testing, its predictive ability is determined. This determination is made by comparing the full model with the reduced model.

To determine if the acceptable full model is a more accurate predictor than the reduced model, the full and reduced regression models are developed with the last 12 data points omitted. Then, using these models, omitted values (which were known but not used in estimating the model coefficients) are predicted. Then, an evaluation of the deviation of the predicted values from the observed values, for both the full and reduced models, is accomplished.

The comparison is made using both a statistical test (ST3) and a criterion test (CT3). The statistical test is used to determine whether the full model is significantly more accurate than the reduced model in predicting the labor hour values omitted in the prediction simulation. Where the full model may be found to be a significantly better predictor based on the statistical test, a criterion test is then applied to establish whether the improved predictive ability of the full model has a practical significance as well.

Statistical Test

The statistical test (ST3) is performed to determine if the average absolute deviation of the full model ($|\overline{D}_F|$) is significantly less than that of the reduced model ($|\overline{D}_R|$). The average absolute deviation for each model is computed by taking the absolute value of the difference between the actual and predicted direct labor hours occurring in each test situation, then separately summing the absolute deviations for each model in all test situations (2:33).

Statistically, the null and alternate hypotheses are:

H_O: $|\bar{D}_R| \leq |\bar{D}_F|$

H_A: $|\bar{D}_R| > |\bar{D}_F|$.

This hypothesis is tested using the following format:

(1) State the null and alternate hypotheses.

(2) State the alpha level (level of significance).

(3) State the test statistic. The test statistic for statistical test three will be the Student's t test.

(4) State the Decision Rule. The Decision Rule for ST3 will be to reject H_O if $t > t_c(0.05)$, where:

$$t = (|\bar{D}_R| - |\bar{D}_F|)/ \sqrt{(S_R^2/N) + S_F^2/N)}$$

(5) State the Decision based upon the Decision Rule.

In the above Decision Rule, the variables are defined as follows:

S_R^2 represents the variance of the distribution of deviations obtained with the reduced model,

S_F^2 represents the variance of the distribution of deviations obtained with the full model,

N represents the number of test situations, and

t_c represents the critical t value obtained from a table of Student's t critical values (17:208-215).

Criterion Test

Where the improved predictive ability of the `full model over the reduced model may be shown to be statistically significant, the model will then be subjected to a test of practical significance. This criterion test (CT3) is necessary because (1) the reduced model, although shown to be a statistically less accurate predictor, could still be sufficiently accurate for practical application, or (2) the full model, although shown to be a statistically better predictor than the reduced model, could still be so inaccurate as to be of no value in practical application. In either instance, the addition of the acceptance rate variable would not be considered worthwhile from a cost/benefit standpoint (2:34).

To perform the criterion test (CT3), the individual deviations computed for the full and reduced models in each test situation under statistical test three (ST3) are converted into a measure of deviation expressed as a percentage of the actual direct labor hours. The use of percentage facilitates later comparison of results between this program and other programs whose values for direct labor hours are relatively large. Two categories are then established for the deviations.

These categories provide a basis for comparison of the predictive ability of the two models. When percentage deviations fall in the range greater than five percent to ten percent or less, the predictive ability is categorized as good. When percentage deviations are five percent or less, the predictive ability is categorized as excellent. The number of test situations in which the percentage deviations fall into each category is then separately summed for the full and reduced models. Totals for each category and model are then subjectively compared and the model with the greater total number of good and excellent predictions is judged to have the better practical predictive ability (2:35).

SUMMARY

Historical production (acceptance) data will be analyzed using least squares multiple linear regression. The research hypothesis will then be tested using the statistical and criterion tests described in this chapter.

The model's acceptability for testing is evaluated using two statistical tests and two criterion tests. If all tests are passed, the full model is then evaluated for predictive ability. The conclusion sought is that the acceptance rate is a significant factor in determining direct labor hour requirements for missile production.

The predictive ability of the model is evaluated using one statistical test and one criterion test. If both tests are passed, the full model is shown to have better practical predictive ability than the reduced model.

Certain assumptions are necessary for the regression model to be appropriate. The strength and validity of the conclusions drawn from the research hypothesis are dependent on the applicability of these assumptions. Further, the methodology contains certain limitations which must be considered. A summary of the assumptions and limitations follows.

Assumptions

(1) Historical data obtained from the manufacturer were recorded accurately.

(2) Multicollinearity did not impair the short-range predictive ability of the models.

(3) Data measurements and transformations were accurate.

(4) No significant loss of data precision was induced by the logarithmic transformation of the data used to facilitate multiple linear regression.

(5) The error terms had a normal distribution with a mean of zero and constant variance, and they were statistically independent (2:41-44).

Limitations

(1) Subjective analysis was required to assess the validity of the assumptions concerning error terms.

(2) Information derived from the data apply only to the program being studied in this research (...4).

(3) Funding limitation precluded incorporating the assembly and test components into this research. This research models only the fabrication component and the total model used in the Allen/Farr research.

CHAPTER III

DATA ANALYSIS AND EVALUATION

This chapter presents analysis of the efficacy of using the DD Form 250 Maverick missile acceptance data as a proxy for actual production rate. Utilizing the methodology presented in Chapter II, six regression models were tested for acceptability. The six models differ in the direct labor hour variable (Y_i) as follows:

Model One = (Y_t) = total direct labor hours,

Model Two = (Y_{tu}) = unit index portion of total direct labor hours,

Model Three = (Y_{tsh}) = standard hours portion of total direct labor hours,

Model Four = (Y_f) = fabrication direct labor hours,

Model Five = (Y_{fu}) = unit index portion of fabrication direct labor hours, and

Model Six = (Y_{fsh}) = standard hours portion of fabrication direct labor hours.

Following the acceptance testing for these six models, those models found to be acceptable are tested to determine their predictive ability and then are compared with the reduced model.

PRESENTATION OF MODELS AND ACCEPTABILITY TESTS

Model One

Model One is presented below. The raw data and results of each statistical/criterion test are presented in Tables 4, 5, and 6.

Reduced Model:

$$Y_t = B_o \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_t) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_t = B_o \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_t) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

Y_t = total direct labor hours/equivalent unit/accounting month,

X_1 = cumulative output plot point (cumulative units at end of accounting month),

X_2 = DD Form 250 acceptance rate/accounting month.

Model Two

Model Two is presented below. The raw data and results of each statistical/criterion test are presented in Tables 7, 8, and 9.

Reduced Model:

$$Y_{tu} = B_o \cdot X_1^{B_1}$$

or in logarithmic form:

$$Log(Y_{tu}) = Log(B_o) + B_1 \cdot Log(X_1)$$

Full Model:

$$Y_{tu} = B_o \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$Log(Y_{tu}) = Log(B_o) + B_1 \cdot Log(X_1) + B_2 \cdot Log(X_2)$$

where:

Y_{tu} = unit index portion of total hours/equivalent unit/accounting month,

X_1 = cumulative output plot point (cumulative units at end of accounting month),

X_2 = DD Form 250 acceptance rate/accounting month.

Model Three

Model Three is presented below. The raw data and results of each statistical/criterion test are presented in Tables 10, 11, and 12.

Reduced Model:

$$Y_{tsh} = B_o \cdot X_1^{B_1}$$

or in logarithmic form:

$$Log(Y_{tsh}) = Log(B_o) + B_1 \cdot Log(X_1)$$

Full Model:

$$Y_{tsh} = B_o \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_{tsh}) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

Y_{tsh} = standard hours portion of total direct labor hours/equivalent unit/accounting month,

X_1 = cumulative output plot point (cumulative units at end of accounting month),

X_2 = DD Form 250 acceptance rate/accounting month.

Model Four

Model Four is presented below. The raw data and results of each statistical/criterion test are presented in Tables 13, 14, and 15.

Reduced Model:

$$Y_f = B_o \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_f) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_f = B_o \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_f) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

Y_f = fabrication direct labor hours/equivalent unit/accounting month,

X_1 = cumulative output plot point (cumulative units at end of accounting month),

X_2 = DD Form 250 acceptance rate/accounting month.

Model Five

Model Five is presented below. The raw data and results of each statistical/criterion test are presented in Tables 16, 17, and 18.

Reduced Model:

$$Y_{fu} = B_o \cdot X_1^{B_1}$$

or in logarithmic form:

$$\text{Log}(Y_{fu}) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1)$$

Full Model:

$$Y_{fu} = B_o \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$\text{Log}(Y_{fu}) = \text{Log}(B_o) + B_1 \cdot \text{Log}(X_1) + B_2 \cdot \text{Log}(X_2)$$

where:

Y_{fu} = unit index portion of fabrication direct labor hours/equivalent unit/accounting month,

X_1 = cumulative output plot point (cumulative units at end of accounting month),

X_2 = DD Form 250 acceptance rate/accounting month.

Model Six

Model Six is presented below. The raw data and results of each statistical/criterion test are presented in Tables 19, 20, and 21.

Reduced Model:

$$Y_{fsh} = B_o \cdot X_1^{B_1}$$

or in logarithmic form:

$$Log(Y_{fsh}) = Log(B_o) + B_1 \cdot Log(X_1)$$

Full Model:

$$Y_{fsh} = B_o \cdot X_1^{B_1} \cdot X_2^{B_2}$$

or in logarithmic form:

$$Log(Y_{fsh}) = Log(B_o) \cdot B_1 \cdot Log(X_1) + B_2 \cdot Log(X_2)$$

where:

Y_{fsh} = standard hours for fabrication direct labor hours/equivalent unit/accounting month,

X_1 = cumulative output plot point (cumulative units at end of accounting month),

X_2 = DD Form 250 acceptance rate/accounting month.

TABLE 4

MODEL ONE - RAW DATA

(Total Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated B_o	954.16	984.48
Estimated B_1	-0.24	-0.22
Estimated B_2	---	-0.04
Data for ST1		
F Ratio	765.40	409.96
F Critical	---	3.15
Data for ST2		
F Statistic	---	5.25
F Critical	---	4.00
Data for CT1		
KS Statistic	---	.26
KS Critical	---	.16
Durbin-Watson Statistic	---	1.02
Durbin-Watson Critical (d_U/d_L)	---	1.67/1.55
Data for CT2		
R^2 Log	.921	.927
R^2 Actual	.918	.898

TABLE 5

MODEL ONE - ST1 & ST2 RESULTS

Statistical Test One Results

(1) H_O: B_1 and $B_2 = 0$

H_A: $B_1 \neq 0$ and/or $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F-ratio is greater than F*, reject H_o, else cannot reject H_O.

(5) Decision: F-Ratio = 409.96
F* = 3.15

409.96 is greater than 3.15, so reject H_O.

Statistical Test Two Results

(1) H_O: $B_2 = 0$

H_A: $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F Statistic is greater than F*, reject H_O, else cannot reject H_O.

(5) Decision: F Statistic = 5.25
F* = 4.00

5.25 is greater than 4.00, so reject H_O.

TABLE 6

MODEL ONE - CT1 & CT2 RESULTS

Criterion Test One Results
Test of Constant Variance of Residuals: The assumption of constant variance of residuals cannot be made because of discernible patterns.
Test of Independence of Residuals: (1) H_O: ρ is greater than 0 H_A: $\rho = 0$ (2) $\alpha = 0.05$ (3) Test Statistic: Durbin-Watson (4) Decision Rule: If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive. (5) Decision: $D = 1.02$, $d_L = 1.55$, $d_U = 1.67$. 1.02 is less than 1.67, so conclude H_O.
Test of Normal Distribution of Residuals: (1) H_O: $KS \geq D(n)_c$ H_A: $KS < D(n)_c$ (2) $\alpha = 0.05$ (3) Test Statistic: KS (4) Decision Rule: If KS is less than $D(n)_c$, reject H_O. (5) Decision: $KS = .26$, $D(n)_c = .16$. .26 is greater than .16, so cannot reject H_O.
Criterion Test Two Results
R^2 (Actual) = .898 and is greater than .75. So, model cannot be rejected as inappropriate for this test.

TABLE 7

MODEL TWO - RAW DATA

(Unit Index for Total Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated B_o	45.34	49.29
Estimated B_1	-0.21	-0.15
Estimated B_2	---	-0.11
<u>Data for ST1</u>		
F Ratio	360.54	279.32
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	31.50
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.22
KS Critical	---	.16
Durbin-Watson Statistic	---	1.22
Durbin-Watson Critical (d_U/d_L)	---	1.67/1.55
<u>Data for CT2</u>		
R^2 Log	.845	.896
R^2 Actual	.878	.855

TABLE 8

MODEL TWO - ST1 & ST2 RESULTS

Statistical Test One Results

(1) H_O: B_1 and $B_2 = 0$

H_A: $B_1 \neq 0$ and/or $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F-ratio is greater than F*, reject H_O, else cannot reject H_O.

(5) Decision: F-Ratio = 279.32
F* = 3.15

279.32 is greater than 3.15, so reject H_O.

Statistical Test Two Results

(1) H_O: $B_2 = 0$

H_A: $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F Statistic is greater than F*, reject H_O, else cannot reject H_O.

(5) Decision: F Statistic = 31.50
F* = 4.00

31.50 is greater than 4.00, so reject H_O.

TABLE 9

MODEL TWO - CT1 & CT2 RESULTS

Criterion Test One Results

Test of Constant Variance of Residuals: The assumption of constant variance of residuals cannot be made because of discernible patterns.

Test of Independence of Residuals:

(1) H_O: ρ is greater than 0
H_A: $\rho = 0$

(2) $\alpha = 0.05$

(3) Test Statistic: Durbin-Watson

(4) Decision Rule: If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive.

(5) Decision: = 1.22 1.22 is less than 1.67, so conclude H_O.
$d_L = 1.55$
$d_U = 1.67$

Test of Normal Distribution of Residuals:

(1) H_O: $KS \geq D(n)_c$
H_A: $KS < D(n)_c$

(2) $\alpha = 0.05$

(3) Test Statistic: KS

(4) Decision Rule: If KS is less than $D(n)_c$, reject H_O.

(5) Decision: KS = .22 .22 is greater than .16, so cannot reject H_O.
$D(n)_c = .16$

Criterion Test Two Results

R^2 (Actual) = .855 and is greater than .75. So, model cannot be rejected as inappropriate for this test.

TABLE 10

MODEL THREE - RAW DATA

(Standard Hours for Total Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated B_o	86.27	83.00
Estimated B_1	-0.06	-0.09
Estimated B_2	---	0.05
<u>Data for ST1</u>		
F Ratio	173.66	174.50
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	49.01
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.13
KS Critical	---	.16
Durbin-Watson Statistic	---	1.46
Durbin-Watson Critical (d_U/d_L)	---	1.67/1.55
<u>Data for CT2</u>		
R^2 Log	.725	.843
R^2 Actual	.694	.824

TABLE 11

MODEL THREE - ST1 & ST2 RESULTS

Statistical Test One Results

(1) H_0: B_1 and $B_2 = 0$

H_A: $B_1 \neq 0$ and/or $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F-ratio is greater than F*, reject H_0, else cannot reject H_0.

(5) Decision: F-Ratio = 174.50
F* = 3.15
174.50 is greater than 3.15, so reject H_0.

Statistical Test Two Results

(1) H_0: $B_2 = 0$

H_A: $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F Statistic is greater than F*, reject H_0, else cannot reject H_0.

(5) Decision: F Statistic = 49.01
F* = 4.00
49.01 is greater than 4.00, so reject H_0.

TABLE 12

MODEL THREE - CT1 & CT2 RESULTS

Criterion Test One Results
Test of Constant Variance of Residuals: The assumption of constant variance of residuals can be made because of indiscernible patterns.
Test of Independence of Residuals:
(1) H_O: ρ is greater than 0 H_A: $\rho = 0$
(2) $\alpha = 0.05$
(3) Test Statistic: Durbin-Watson
(4) Decision Rule: If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive.
(5) Decision: $D = 1.46$, $d_L = 1.55$, $d_U = 1.67$. 1.46 is less than 1.67, so conclude H_O.
Test of Normal Distribution of Residuals:
(1) H_O: $KS \geq D(n)_c$ H_A: $KS < D(n)_c$
(2) $\alpha = 0.05$
(3) Test Statistic: KS
(4) Decision Rule: If KS is less than $D(n)_c$, reject H_O.
(5) Decision: $KS = .13$, $D(n)_c = .16$. .13 is less than .16, so reject H_O.
Criterion Test Two Results
R^2 (Actual) = .824 and is greater than .75. So, model cannot be rejected as inappropriate for this test.

TABLE 13

MODEL FOUR - RAW DATA

(Fabrication Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated B_o	101.55	100.21
Estimated B_1	-0.105	-0.08
Estimated B_2	---	-0.04
<u>Data for ST1</u>		
F Ratio	74.82	41.78
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	4.63
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.13
KS Critical	---	.16
Durbin-Watson Statistic	---	1.34
Durbin-Watson Critical (d_U/d_L)	---	1.67/1.55
<u>Data for CT2</u>		
R^2 Log	.531	.562
R^2 Actual	.530	.546

TABLE 14

MODEL FOUR - ST1 & ST2 RESULTS

Statistical Test One Results

(1) H_0: B_1 and $B_2 = 0$

H_A: $B_1 \neq 0$ and/or $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F-ratio is greater than F*, reject H_0, else cannot reject H_0.

(5) Decision: F-Ratio = 41.78
F* = 3.15

41.78 is greater than 3.15, so reject H_0.

Statistical Test Two Results

(1) H_0: $B_2 = 0$

H_A: $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F Statistic is greater than F*, reject H_0, else cannot reject H_0.

(5) Decision: F Statistic = 4.63
F* = 4.00

4.63 is greater than 4.00, so reject H_0.

TABLE 15

MODEL FOUR - CT1 & CT2 RESULTS

Criterion Test One Results

Test of Constant Variance of Residuals: The assumption of constant variance of residuals cannot be made because of discernible patterns.

Test of Independence of Residuals:

(1) H_0: ρ is greater than 0
H_A: $\rho = 0$

(2) $\alpha = 0.05$

(3) Test Statistic: Durbin-Watson

(4) Decision Rule: If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive.

(5) Decision: $D = 1.34$, $d_L = 1.55$, $d_U = 1.67$. 1.34 is less than 1.67, so conclude H_O.

Test of Normal Distribution of Residuals:

(1) H_O: $KS \geq D(n)_c$
H_A: $KS < D(n)_c$

(2) $\alpha = 0.05$

(3) Test Statistic: KS

(4) Decision Rule: If KS is less than $D(n)_c$, reject H_O.

(5) Decision: $KS = .13$, $D(n)_c = .16$. .13 is less than .16, so reject H_O.

Criterion Test Two Results

R^2 (Actual) = .546 and is less than .75. So, model is rejected as inappropriate for this test.

TABLE 16

MODEL FIVE - RAW DATA

(Unit Index for Fabrication Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated B_o	4.29	4.06
Estimated B_1	-0.08	-0.04
Estimated B_2	---	-0.07
<u>Data for ST1</u>		
F Ratio	45.02	37.61
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	18.36
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.12
KS Critical	---	.16
Durbin-Watson Statistic	---	1.81
Durbin-Watson Critical (d_U/d_L)	---	1.67/1.55
<u>Data for CT2</u>		
R^2 Log	.406	.536
R^2 Actual	.450	.508

TABLE 17

MODEL FIVE - ST1 & ST2 RESULTS

Statistical Test One Results

(1) H_O: B_1 and $B_2 = 0$

H_A: $B_1 \neq 0$ and/or $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F-ratio is greater than F*, reject H_O, else cannot reject H_O.

(5) Decision: F-Ratio = 37.61
F* = 3.15

37.61 is greater than 3.15, so reject H_O.

Statistical Test Two Results

(1) H_O: $B_2 = 0$

H_A: $B_2 \neq 0$

(2) $\alpha = 0.05$

(3) Test Statistic: F-Test

(4) Decision Rule: If the F Statistic is greater than F*, reject H_O, else cannot reject H_O.

(5) Decision: F Statistic = 18.36
F* = 4.00

18.36 is greater than 4.00, so reject H_O.

TABLE 18

MODEL FIVE - CT1 & CT2 RESULTS

Criterion Test One Results

Test of Constant Variance of Residuals: The assumption of constant variance of residuals can be made because of indiscernible patterns.

Test of Independence of Residuals:

(1) H_O: ρ is greater than 0
H_A: $\rho = 0$

(2) $\alpha = 0.05$

(3) Test Statistic: Durbin-Watson

(4) Decision Rule: If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive.

(5) Decision: $D = 1.81$, $d_L = 1.55$, $d_U = 1.67$. 1.81 is greater than 1.55, so conclude H_A.

Test of Normal Distribution of Residuals:

(1) H_O: $KS \geq D(n)_c$
H_A: $KS < D(n)_c$

(2) $\alpha = 0.05$

(3) Test Statistic: KS

(4) Decision Rule: If KS is less than $D(n)_c$, reject H_O.

(5) Decision: $KS = .12$, $D(n)_c = .16$. .12 is less than .16, so reject H_O.

Criterion Test Two Results

R^2 (Actual) = .508 and is less than .75. So, model is rejected as inappropriate for this test.

TABLE 19

MODEL SIX - RAW DATA

(Standard Hours for Fabrication Hours Per Unit)

TEST ITEMS	REDUCED MODEL	FULL MODEL
Estimated B_o	25.75	26.76
Estimated B_1	-0.03	-0.06
Estimated B_2	---	0.05
<u>Data for ST1</u>		
F Ratio	8.99	13.41
F Critical	---	3.15
<u>Data for ST2</u>		
F Statistic	---	15.82
F Critical	---	4.00
<u>Data for CT1</u>		
KS Statistic	---	.15
KS Critical	---	.16
Durbin-Watson Statistic	---	1.97
Durbin-Watson Critical (d_U/d_L)	---	1.67/1.55
<u>Data for CT2</u>		
R^2 Log	.120	.292
R^2 Actual	.111	.268

TABLE 20

MODEL SIX - ST1 & ST2 RESULTS

Statistical Test One Results
(1) H_0: B_1 and $B_2 = 0$ H_A: $B_1 \neq 0$ and/or $B^2 \neq 0$
(2) $\alpha = 0.05$
(3) Test Statistic: F-Test
(4) Decision Rule: If the F-ratio is greater than F*, reject H_0, else cannot reject H_0.
(5) Decision: F-Ratio = 13.41 F* = 3.15 13.41 is greater than 3.15, so reject H_0.

Statistical Test Two Results
(1) H_0: $B_2 = 0$ H_A: $B_2 \neq 0$
(2) $\alpha = 0.05$
(3) Test Statistic: F-Test
(4) Decision Rule: If the F Statistic is greater than F*, reject H_0, else cannot reject H_0.
(5) Decision: F Statistic = 15.82 F* = 4.00 15.82 is greater than 4.00, so reject H_0.

TABLE 21

MODEL SIX - CT1 & CT2 RESULTS

Criterion Test One Results
Test of Constant Variance of Residuals: The assumption of constant variance of residuals can be made because of indiscernible patterns.

Test of Independence of Residuals:

(1) H_O: ρ is greater than 0
H_A: ρ = 0

(2) α = 0.05

(3) Test Statistic: Durbin-Watson

(4) Decision Rule: If D is greater than d_L, conclude H_A; if D is less than d_U, conclude H_O; if $d_L \leq D \leq d_U$, test is inconclusive.

(5) *Decision:* $D = 1.97$ 1.97 is greater than 1.55, so conclude H_A.
$d_L = 1.55$
$d_U = 1.67$

Test of Normal Distribution of Residuals:

(1) H_O: $KS \geq D(n)_c$
H_A: $KS < D(n)_c$

(2) α = 0.05

(3) Test Statistic: KS

(4) Decision Rule: If KS is less than $D(n)_c$, reject H_O.

(5) Decision: KS = .15   .15 is less than .16, so reject H_O.
$D(n)_c$ = .16

Criterion Test Two Results
R^2 (Actual) = .268 and is less than .75. So, model is rejected as inappropriate for this test.

SUMMARY OF MODEL ACCEPTABILITY TEST RESULTS

Each of the six models described earlier was subjected to two statistical tests and two criterion tests to evaluate their overall acceptability as suitable models for further predictive ability testing. Below is a concise summary of each model's score (pass/fail) for each of the statistical and criterion tests presented in the previous section. It is important to remember that a model must pass all four of these tests in order to be found acceptable for further predictive ability testing.

Model One

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus confirms the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Failed. Could not assume constant variance of residuals because of discernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus, H_0 was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Failed. The calculated KS Statistic was greater than the critical value listed in the table. Thus, the data were not considered to be normally distributed.

Criterion Test Two (CT2). Passed. The R^2 (Actual) was greater than .75. Thus, the model explains the variation in direct labor hours during the regression analysis.

In summary, Model One passed ST1, ST2, and CT2. It failed all tests contained in CT1 and is, therefore, not acceptable for further testing.

Model Two

Statistical Test One (ST1). Passed. The F-ratio is greater than F critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Failed. Could not assume constant variance of residuals because of discernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus, H_0 was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Failed. The calculated KS Statistic was greater than the critical value listed in the table. Thus, the data was not considered to be normally distributed.

Criterion Test Two (CT2). Passed. The R^2 (Actual) was greater than .75. Thus, the model explains the variation in direct labor hours during the regression analysis.

In summary, Model Two reacted identically to Model One. Model Two passed ST1, ST2, and CT2. It failed all tests contained in CT1 and is, therefore, not acceptable for further testing.

Model Three

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data is added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. Test of constant variance of residuals. Passed. Constant variance of residuals can be assumed because of indiscernible patterns.

b. Test of independence of residuals. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus, H_0 was concluded which indicates the residuals are dependent.

c. Test of normal distribution of residuals. Passed. The calculated KS Statistic was less than the critical value listed in the table. Thus, the data is considered to be normally distributed.

Criterion Test Two (CT2). Passed. The R^2 (Actual) was greater than .75. Thus, the model explains the variation in direct labor hours during the regression analysis.

In summary, Model Three came very close to passing all four tests. Model Three passed all tests except the Test of Independence of Residuals in CT1. This failure was marginal but was enough to deem Model Three unacceptable for further testing.

Model Four

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall failure.

a. *Test of constant variance of residuals*. Failed. Could not assume constant variance of residuals because of discernible patterns.

b. *Test of independence of residuals*. Failed. The calculated Durbin-Watson Statistic was less than the upper limit of the table value. Thus, H_0 was concluded which indicates the residuals are dependent.

c. *Test of normal distribution of residuals*. Passed. The calculated KS Statistic was less than the critical value listed in the table. Thus, the data are considered to be normally distributed.

Criterion Test Two (CT2). Failed. The R^2 (Actual) was less than .75. Thus, the model does not explain the variation in direct labor hours during the regression analysis.

In summary, Model Four passed ST1, ST2 and failed CT1 and CT2. Therefore, Model Four is not acceptable for further testing.

Model Five

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall pass.

a. Test of constant variance of residuals. Passed. Constant variance of residuals can be assumed because of indiscernible patterns.

b. Test of independence of residuals. Passed. The calculated Durbin-Watson Statistic is greater than the lower limit of the table value. Thus, H_A was concluded which indicates the residuals are independent.

c. Test of normal distribution of residuals. Passed. The calculated KS Statistic was less than the critical value listed in the table. Thus, the data were considered to be normally distributed.

Criterion Test Two (CT2). Failed. The R^2 (Actual) is less than .75. Thus, the model does not explain the variation in direct labor hours during the regression analysis.

In summary, Model Five came very close to being acceptable for further testing. All tests were passed except for CT2. Thus, the model is not acceptable for further testing.

Model Six

Statistical Test One (ST1). Passed. The F-ratio is greater than F Critical and thus determines the ability of the model to explain the variance of the dependent variable.

Statistical Test Two (ST2). Passed. The F Statistic is greater than F Critical. Thus, the model adequately explains the additional variation in direct labor hours per missile when the DD Form 250 data are added to the reduced model.

Criterion Test One (CT1). Overall pass.

a. Test of constant variance of residuals. Passed. Constant variance of residuals can be assumed because of indiscernible patterns.

b. Test of independence of residuals. Passed. The calculated Durbin-Watson Statistic is greater than the lower limit of the table value. Thus, H_A was concluded which indicates the residuals are independent.

c. Test of normal distribution of residuals. Passed. The calculated KS Statistic was less than the critical value listed in the table. Thus, the data were considered to be normally distributed.

Criterion Test Two (CT2). Failed. The R^2 (Actual) is less than .75. Thus, the model does not explain the variation in direct labor hours during the regression analysis.

In summary, Model Six is identical to Model Five. All tests were passed except for CT2 and the model is not acceptable for further testing.

For ease of comparison, Table 22 further condenses the results of the acceptability testing.

SUMMARY OF RESEARCH HYPOTHESIS ANALYSIS

The research hypothesis stated that the predictive ability of Smith's model is not compromised by the substitution of the DD Form 250 acceptance rate for the actual production rate variable.

In the Allen/Farr research effort, it was concluded that the addition of the production rate variable explained a significant amount of variation in direct labor hours. Additionally, Allen/Farr concluded that the addition of the production rate variable (full model) further enhanced the basic model's (reduced model's)

TABLE 22

SUMMARY OF MODEL
ACCEPTABILITY TEST RESULTS

MODEL NUMBER	TEST CATEGORY			
	ST1	ST2	CT1	CT2
1	Pass	Pass	Fail	Pass
2	Pass	Pass	Fail	Pass
3	Pass	Pass	Fail	Pass
4	Pass	Pass	Fail	Fail
5	Pass	Pass	Pass	Fail
6	Pass	Pass	Pass	Fail

predictive ability.

This research effort substituted the DD Form 250 acceptance rate for the production rate variable in the Allen/Farr data and concluded very definite results. Not one of the six models tested with this proxy were found acceptable for further predictive ability testing. Because Allen/Farr experienced satisfactory results with their models, it can only be concluded that acceptance rate in no way correlates with actual production rate for the Maverick missile data and is not a reliable proxy for actual production rate data.

Both of the statistical tests (ST1 and ST2) indicated full support for the research hypothesis in all six cases. The criterion tests (CT1 and CT2), however, produced mixed results.

Referring to Table 22, it is interesting to note that whenever Models One, Two, or Three failed CT1, these same models passed CT2. Model Four failed both CT1 and CT2. Equally interesting is that Models Five and Six passed CT1 but failed CT2. These comparisons, together with all models passing ST1 and ST2, comprise the only noticeable patterns in the test results.

The results of testing for Statistical Test One (ST1) in every model demonstrated that the explanatory power added by the acceptance rate data was statistically significant at the 0.05 level of significance. Notwithstanding these excellent results, all of the models either failed the KS test for normality of residuals, the Durbin-Watson test for independence of residuals, the constant variance test, or a combination of these tests.

In summary, the results did not support the research hypothesis for the Maverick data used by Allen/Farr. In fact, the models were not even acceptable for further predictive ability testing. Chapter IV will contain the summary, conclusions, and recommendations for these research results.

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The years following World War II have presented an era of increasing complexity in DOD weapon systems acquisitions. Air Force managers attempting to plan the acquisition, operation, and maintenance of major weapon systems face an increasing array of obstacles in the form of inflation, spiraling cost of energy, and international political instability. While the task has become more difficult, the need for more accurate cost estimating has become more obvious.

Direct labor is one of the most significant cost elements in a major system acquisition and experience has shown that direct labor costs are most often estimated using learning curve analysis.

SUMMARY

Literature Review

Learning curve models were in use as early as the 1920s and even more interest was generated as a result of the aerospace industry's experience during World War II. Over the years, numerous variations of the basic learning curve model have been investigated. Since the DOD is constantly faced with budgetary and political controls that cause program accelerations and decelerations, the variation that has the most promise for DOD application is the model that considers the effect of production rate variations.

It is possible, however, that this production rate variable is not always accessible or even available to the DOD researcher interested in projecting the costs of a future DOD major weapons system. When these data are not available, a proxy must be developed as a substitute for the production rate variable. This research effort has investigated the use of acceptance rate as a reliable proxy for the production rate variable in the attempt to predict direct labor costs for the acquisition of a major weapon system.

Most of the research on the effect of production rate changes concluded that production rate is a significant determinant of direct labor costs. Smith developed a learning curve model that included a production rate variable, tested the model on airframe production programs and concluded that the model yielded promising results. Smith's model has been applied to other airframe programs, avionics, and engines, and now has been extended to air-launched missiles in the form of the acceptance rate proxy.

The Model

The production rate model, which Smith called the full model, is presented as follows:

$$Y = B_o \cdot X_1^{B_1} \cdot X_2^{B_2} \cdot 10^e$$

where the variables are described as follows:

Y represents direct labor hours,

X_1 represents cumulative output,

X_2 represets the production rate (acceptance rate in this research),

e represents the variation which remains unexplained by the variables in the model, and

B_o, B_1, and B_2 are regression coefficients.

To facilitate regression analysis, the model is linearized using logarithms as follows:

$$\text{Log } Y = \text{Log } B_o + B_1 \text{ Log } X_1 + B_2 \text{ Log } X_2 + e \quad .$$

The reduced model is identical to the full model except that the reduced model does not include the production rate variable (2:98).

Research Objective

As stated in Chapter I, the objective of this research was to determine if the DD Form 250 acceptance rate can be substituted for the actual production rate variable contained in Smith's model without compromising the predictive ability of that model.

Methodology

Linear regression analysis of the logarithmic forms of the full and reduced models was employed to achieve the research objective. Data were obtained from the Maverick missile production program and the treatment of these data is described in Chapter II. Testing of the research hypothesis first required determining if the model, using the DD Form 250 acceptance rate data, is acceptable. Then, if the model had been found to be acceptable, the predictive ability of the model would have been compared to the predictive ability of the model using actual production rate data to determine if any compromise exists.

To determine if a model using the DD Form 250 acceptance data is acceptable required two steps. The first step examined the statistical significance of the model's regression coefficients by regression analysis of historical production data. This step was composed of two statistical steps. The second step involved the use of two criterion tests to evaluate the appropriateness of the model for this data. The dependent variable of the full model, in log-linear form, was subjected to regression analysis. The independent variables were the logarithms of cumulative output and the DD Form 250 acceptance rate.

After the full model, with the DD Form 250 rate incorporated, is accepted as the result of model acceptability testing, its predictive ability can be determined. This determination is made by comparing the full model with the reduced model.

To determine if the acceptable full model is a more accurate predictor than the reduced model, the full and reduced regression models were developed with the last 12 data points omitted. Then, using these models, omitted values would be predicted. Then, an evaluation of the deviation of the predicted values from the observed values, for both the full and reduced models, would have been accomplished.

Had the models been found to be acceptable for further predictive ability testing, the comparison would have been made using both a statistical test and a criterion test. The statistical test is used to determine whether the full model is significantly more accurate than the reduced model in predicting the labor hour values omitted in the prediction simulation. Where the full model is found to be a significantly better predictor based on the statistical test, a criterion test is then applied to establish whether the improved predictive ability of the full model has a practical significance as well.

AD-A135 480 THE EFFECT OF SUBSTITUTING THE DD FORM 250 ACCEPTANCE RATE FOR ACTUAL PRO..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. G D GENTRY

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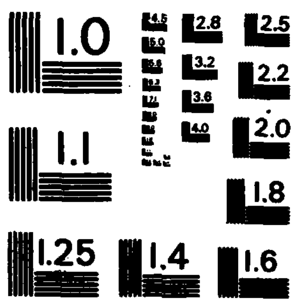

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CONCLUSIONS

This research provides three primary conclusions. First, the production rate, as substituted by the DD Form 250 acceptance rate, failed to explain a significant amount of variation in direct labor hours in the six models examined. Of the six models, none produced acceptable results using the acceptance rate proxy. There was no evident support to conclude that the DD Form 250 acceptance rate variable should be considered as a reliable proxy for actual production rate when evaluating missile production programs.

Second, the results of the predictive ability comparisons were not able to be tested because the model acceptability tests were failed in all six cases. Thus, the DD Form 250 acceptance data, as a proxy, proved to be unreliable as a substitute for actual production data in the prediction of direct labor costs.

Third, as a result of hypotheses testing, it is concluded that Smith's model has no potential for missile production programs when using the DD Form 250 acceptance rate as a proxy for actual production rate. This conclusion is based solely on this research and in no way infers that other proxies, such as delivery rate data, should not be investigated.

RECOMMENDATIONS

This type of learning curve analysis has potential application anywhere that learning curve theory applies and should be used widely within DOD to test the effects of any moderating variable on the cost of a major weapon system acquisition.

A related recommendation is that the research applied in this effort be conducted on delivery rate as well as acceptance rate for other production programs within the DOD. The ease of obtaining these data, compared with the difficulty of obtaining actual production data in some cases, makes the use of proxies an attractive alternative for DOD researchers interested in predicting the direct labor costs of major acquisition.

Finally, it is important to reiterate the Allen/Farr recommendation that a checklist guide to the practical use of Smith's model be developed. Such a guide would encourage the use of the model by those who are uneasy with statistics and the seeming complexity of the model (2:103).

APPENDIX

THE COMPUTER PROGRAM PRODRATE

The revised version of PRODRATE developed for this research significantly reduced user costs and increased program usability. PRODRATE users can now perform essential residual analysis with the additional PRODRATE statistics and the statistical packages already incorporated in the basic computer program. In addition, several options are now available to drastically decrease run-time and increase the usability of the prediction routines.

This section lists the computer program PRODRATE in its entirety. The original program was developed by Colonel Larry L. Smith, and later modified by Captain David Y. Stevens, Captain Scott C. Allen, and Captain Charles M. Farr. The version listed incorporates the original program and all modifications. The actual program used during this research is the program presented in this section.

```
C*****************************************************************************************
C
C     PPPPP  RRRRR  OOOOO  DDD    RRRRR  AAAAA  TTTTT  EEEEE
C     P   P  R   R  O   O  D  D   R   R  A   A    T    E
C     PPPPP  RRRRR  O   O  D   D  RRRRR  AAAAA    T    EEE
C     P      R  R   O   O  D  D   R  R   A   A    T    E
C     P      R   R  OOOOO  DDD    R   R  A   A    T    EEEEE
C
C*****************************************************************************************
C
C                   THE CUMULATIVE PRODUCTION AND PRODUCTION RATE COST MODEL
C
C     THE ORIGINAL PROGRAMMER IS LT COL LARRY L. SMITH [AFIT/LSGM AV# 785-5296] - JAN 1978
C     LATER MODIFIED BY CAPT DAVID T. STEVENS [ESD/PKC AV# 478-3462] -JUNE 1979
C     THIS MODIFIED VERSION WAS PROGRAMMED BY CAPTS SCOTT ALLEN, TOM SANDMAN, AND
C     MIKE FARR [ASD/PM, AFIT LS, AND ASD/PM, RESPECTIVELY] -JUNE 1980
C*****************************************************************************************
 5 FORMAT(1H1,//,100("*"),//,1X,40X,"PRODRATE INSTRUCTIONS",//,1X,100("*"),//,
 &  "     THIS PROGRAM IS DESIGNED TO EVALUATE THE VARIATION IN DIRECT LABOR REQUIREMENTS AS A ",/,
 &  " FUNCTION OF CUMULATIVE PRODUCTION AND PRODUCTION RATE.  IN ADDITION, THE ANALYST MAY ",/,
 &  " COMPARE THE RESULTS OBTAINED FROM THE STANDARD LEARNING CURVE WITH THE RESULTS OBTAINED ",/,
 &  " FROM THE CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL.  THE COST MODELS USED IN THIS ",/,
 &  " PROGRAM ARE:",//,
 &  "     1.  REDUCED MODEL [STANDARD LEARNING CURVE MODEL]",//,
 &  "              Y = B0 * (X1 ** B1) * (10 ** E)",//,
 &  "     2.  FULL MODEL [CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL]",//,
 &  "              Y = B0 * (X1 ** B1) * (X2 ** B2) * (10 ** E)",//,
 &  "         WHERE: Y                IS THE DIRECT LABOR REQUIREMENTS",/,
 &  "                X1               IS THE CUMULATIVE PRODUCTION PLOT POINT",/,
 &  "                X2               IS THE PRODUCTION RATE PROXY(E.G. EQUIVALENT UNITS PER MONTH)",/,
 &  "                E                REPRESENTS THE ERROR TERM",/,
 &  "                B0, B1, AND B2  ARE  PARAMETERS DETERMINED BY REGRESSION",//,
 &  "     DATA ARE INPUT BY READING FROM ANY PROPERLY FORMATTED DATA FILE.  YOUR DATA FILE SHOULD ",/,
 &  " BE SAVED TO ANY PERMANENT FILENAME.  YOU WILL BE ASK TO INPUT THE NAME OF YOUR DATA FILE ",/,
 &  " AT THE APPROPRIATE STEP IN THE PROGRAM.  THE NAME OF YOUR DATA FILE CAN NOT EXCEED 8 ",/,
 &  " CHARACTERS.  THE FIRST LINE OF THE DATA FILE MUST CONTAIN A LINE NUMBER AND THE NUMBER OF ",/,
 &  " CASES TO BE READ.  THE DATA IS THEN ENTERED ONE CASE PER LINE IN THE FOLLOWING ORDER: "/
 &  " LINE NUMBER, OBSERVED DIRECT LABOR REQUIREMENT (Y), CUMULATIVE PRODUCTION PLOT POINT (X1),",/,
 &  " AND PRODUCTION RATE PROXY (X2).  THE PROGRAM USES A FREE FIELD READ FORMAT; THEREFORE,",/,
 &  " EACH VARIABLE MUST BE SEPARATED BY AT LEAST ONE SPACE (OR OTHER DELIMITER) BUT NO OTHER",/,
 &  " SPECIAL FORMAT IS REQUIRED.  AN EXAMPLE OF A DATA FILE WITH 5 CASES IS PRESENTED BELOW:",//,
 &  "     100     5",/,
 &  "     101     100     9.5     9.5",/,
 &  "     102     90      30      20.5",/,
 &  "     103     80      55      25",/,
 &  "     104     75      82      27",/,
 &  "     105     71      113     31",//,
 &  " ONE ADVANTAGE OF THIS PROGRAM IS THAT THE RESULTS OBTAINED WILL BE IN THE SAME UNITS AND",/,
 &  " FORM AS THE INPUT DATA.  FOR EXAMPLE, IF YOU ARE WORKING IN DIRECT LABOR HOURS PER MONTH",/,
 &  " AND EQUIVALENT UNITS, THE RESULTS WILL BE IN TERMS OF THESE UNITS.  ALSO, IF YOU WISH TO USE",/,
 &  " A CUMULATIVE AVERAGE APPROACH, ALL YOU NEED DO IS ACCREGATE THE DATA BASE IN THAT MANNER.",//,
 &  "     THE PROGRAM BEGINS BY TRANSFORMING THE INPUT DATA TO COMMON LOGARITHMS.  LOG_LINEAR",/,
```

```
     * REGRESSION IS THEN PERFORMED AS FOLLOWS:  Y  REGRESSED ON  X1, Y  REGRESSED ON  X2, AND",/,
     * FINALLY Y  REGRESSED ON BOTH X1 AND X2.  OBSERVED DIRECT LABOR REQUIREMENTS, PREDICTED",/,
     * DIRECT LABOR REQUIREMENTS, AND RESIDUALS ARE PRINTED IN ORIGINAL (UNTRANSFORMED) FORM FOR",/,
     * EACH REGRESSION SITUATION.  IN ADDITION, SUMMARY STATISTICS ARE PRINTED FOR EACH MODEL.  THE",/,
     * SUMMARY STATISTICS INCLUDE TWO COEFFICIENTS OF DETERMINATION R SQUARED LOG AND R SQUARED",/,
     * ACTUAL.  THE R SQUARED LOG REPRESENTS THE GOODNESS OF FIT OF THE MODEL TO THE TRANSFORMED",/,
     * DATA (LOG FORM).  THE R SQUARED ACTUAL, ON THE OTHER HAND, IS COMPUTED USING THE",/,
     * UNTRANSFORMED RESIDUALS, AND IS REPRESENTATIVE OF HOW WELL THE MODEL FITS THE UNTRANSFORMED",/,
     * DATA.  THE DURBIN-WATSON STATISTIC IS CALCULATED FOR  ASSESSMENT  OF AUTOCORRELATION",/,
     * OF THE RESIDUALS.")
   6 FORMAT(1H1,1X,//,
     *      SEVERAL OPTIONS ARE AVAILABLE WITHIN THIS PROGRAM AND CAN BE SELECTED BY APPROPRIATE",/,
     * ANSWERS TO THE FOLLOWING QUESTIONS:",//,
     *      1.  DO YOU WANT TO CHECK DATA AS IT IS READ FROM FILE ........ AND CONVERTED TO",/,
     *      LOGARITHMS?",//,
     *      YES - WILL CAUSE THE PRINTING OF A LISTING OF THE RATIONAL INPUT DATA AND THE",/,
     *            ASSOCIATED LOGARITHMIC VALUES.",//,
     *      NO  - SUPPRESSES THIS OPTION.",//,
     *      2. COMPLETE PRINTOUT?",//,
     *      YES - WILL CAUSE OUTPUT TO BE PRINTED IN FULL FORMAT AS DESCRIBED ABOVE.",/,
     *      NO - WILL DELETE THE LISTING OF OBSERVED, PREDICTED, AND RESIDUAL VALUES",/,
     *           BETWEEN TABLES OF SUMMARY STATISTICS.  IT WILL ALSO DELETE LISTING OF",/,
     *           INDIVIDUAL MATRICES FOR THE SHORTRANGE PREDICTIVE ABILITY OPTION(I.E.,",/,
     *           ONLY THE SUMMARY TABLE WILL BE LISTED.",//,
     *      3. DO YOU WANT A COMPARISON OF THE SHORTRANGE PREDICTIVE ABILITY OF THE TWO MODELS?",//,
     *      YES - WILL CAUSE THE PREDICTIVE ABILITY TEST OPTION TO BE ACTIVATED AND THE USER WILL",/,
     *           BE TOLD: 'ENTER PREDICTION RANGE (CASE NUMBERS FOR FIRST AND LAST CASES).'",/,
     *           THE USER SHOULD ENTER THE NUMBER OF THE FIRST CASE TO BE PREDICTED FOLLOWED",/,
     *           BY THE LAST CASE TO BE PREDICTED, SEPARATED BY A COMMA.  THE CASE NUMBERS",/,
     *           MUST BE INTEGER VALUES GREATER THAN OR EQUAL TO 2.  THE PREDICTIVE",/,
     *            ABILITY TEST SIMULATES FUTURE PREDICTIONS BY PERFORMING A STEPWISE TRUNCATION OF",/,
     *            THE HISTORICAL DATA.  FOR THIS REASON, AN UPPER LIMITATION ON THE NUMBER OF",/,
     *            CASES TRUNCATED WOULD BE: ((TOTAL NUMBER OF CASES IN DATA FILE) / 2) - 2",/,
     *            FOR EXAMPLE, IF YOUR DATA FILE CONTAINS 50 CASES, YOUR UPPER LIMIT WOULD BE",/,
     *            23 CASES.  THIS, OF COURSE, REPRESENTS ONLY THE MAXIMUM NUMBER OF CASES THAT",/,
     *            COULD BE TRUNCATED.  IN PRACTICE YOU MAY WANT TO TRUNCATE ONLY A SMALL NUMBER OF",/,
     *            CASES.  THUS, IF YOUR DATA IS COLLECTED IN MONTHLY INTERVALS, YOU CAN LOOK AT",/,
     *            THE PREDICTIVE ABILITY OF THE FULL AND REDUCED MODELS FOR AN 18 MONTH TIME SPAN BY",/,
     *           SPECIFYING AN 18 CASE RANGE.  IF YOUR DATA IS COLLECTED IN QUARTERS, YOU CAN LOOK",/,
     *            AT THE PREDICTIVE ABILITY OF BOTH MODELS FOR AN 18 MONTH TIME SPAN BY SPECIFYING",/,
     *            '6'.  AFTER ALL PREDICTIVE ABILITY TEST SITUATIONS ARE PRINTED, THE PROGRAM",/,
     *            PRINTS A SUMMARY OF THE TEST RESULTS.",//,
     *       NO  - SUPPRESSES THIS OPTION.",//,
     *       4.  DO YOU WANT PROJECTION AND SENSITIVITY MATRIX?",//,
     *       YES - WILL CAUSE PRINTING OF PROJECTION AND SENSITIVITY MATRIX.  THIS MATRIX PRESENTS",/,
     *             PROJECTED DIRECT LABOR REQUIREMENTS FOR SELECTED PAIRS OF CUMULATIVE PRODUCTION",/,
     *             PLOT POINTS AND PRODUCTION RATES.  THE PROJECTION INTERVAL FOR THE CUMULATIVE",/,
     *             PRODUCTION PLOT POINT IS 1% OF THE LAST OBSERVED VALUE.  THE PROJECTION VALUES",/,
     *             FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF",/,
     *              THE LAST OBSERVED VALUE OF PRODUCTION RATE.",//,
     *        NO  -SUPPRESSES THIS OPTION.",//,
     * ***SPECIAL NOTE***  THE PREDICTED DIRECT LABOR REQUIREMENTS AND RESIDUALS FOR EACH MODEL",/,
```

```
     *    ARE STORED IN SEPARATE FILES.  THE VALUES FOR THE STANDARD LEARNING CURVE MODEL ARE",/,
     *    STORED IN A FILE CALLED 'STDLEARN'; THE VALUES FOR THE PRODUCTION RATE VARIABLE ALONE",/,
     *    MODEL IN THE FILE 'REDHOURS'; AND THE VALUES FOR THE COMBINED CUM. PRODUCTION AND",/,
     *    PRODUCTION RATE MODEL IN THE FILE 'FULLMODL'.  USERS MAY ACCESS THESE FILES FOR ",/,
     *    RESIDUAL ANALYSIS BY OTHER COPPER IMPACT STATISTICAL PROGRAMS, IF DESIRED.")
C
C
C****************************************************************************************
C     DIMENSIONING VARIABLES
C****************************************************************************************
 ALPHA ANSWER(10),ANS(10)
      FILENAME DATAFILE
      DIMENSION PLOT(150),RATE(150),HRS(150),Y(150),Z1(150),Z2(150),LN(150),
      NEWPLOT(150),PRORATE(15),FHRS(150,15),ADEVR(999),ADEVF(999),RESID(200)
      DATA SUMHRS,SUMX1,SUMX2,SUMY,SSX1,SSX2,SUMX1Y,SUMX2Y,SMX1X2,
      SSE,SSE1,SSE2,SSEL,SSEL1,SSEL2,SSTO,SSTO1,SSTO2,SSTOL,SSTOL1,SSTOL2/21*0/
C****************************************************************************************
C
C     PART I - BEGIN PROGRAM, INSTRUCTIONS, DATA INPUT, DATA TRANSFORMATION, AND OPTION SELECTIONS.
C
C****************************************************************************************
 PRINT 1195
 1195 FORMAT(1X"                               THE CUMULATIVE PRODUCTION AND PRODUCTION RATE COST MODEL")
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     INSTRUCTIONS OPTION SELECTION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
 OPTION NOWARN
 OPEN(FILE='LOGFILE',UNIT=4,ACCESS='LINENO',STATUS='UNKNOWN')
 OPEN(FILE='STDCURVE')
 OPEN(FILE='REDCURVE')
 OPEN(FILE='FULCURVE')
 OPEN(FILE='STDLEARN')
 OPEN(FILE='REDHOURS')
 OPEN(FILE='FULLMODL')
 CLOSE(FILE='STDCURVE')
 CLOSE(FILE='REDCURVE')
 CLOSE(FILE='FULCURVE')
       PRINT 10
    10 FORMAT(1H0"DO YOU WANT INSTRUCTIONS")
  100  INPUT, ANSWER(1)
       IF (ANSWER(1).EQ."NO") GO TO 102
       IF (ANSWER(1).EQ."YES") GO TO 101
       PRINT," ANSWER YES OR NO ONLY PLEASE"
       PRINT," "
       GO TO 100
 101 PRINT 5
 PRINT 6
 102 PRINT,"COMPLETE PRINTOUT"
 INPUT,ANS(3)
 IF(ANS(3).EQ."NO".OR.ANS(3).EQ."YES")GO TO 672
 PRINT,"ANSWER YES OR NO ONLY PLEASE"
 GO TO 102
```

```
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     INPUT THE DATA AND TRANSFORM THE VARIABLES TO LOGARITHMS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C
  672 PRINT 20
   20 FORMAT(1X,"PLEASE ENTER THE NAME OF YOUR DATA FILE")
      INPUT, DATAFILE
      READ(DATAFILE,*)LN(1),NCASES
      DO 30 I=1,NCASES
      READ(DATAFILE,*)LN(I),HRS(I),PLOT(I),RATE(I)
      T(I)  = ALOG10(HRS(I))
      X1(I) = ALOG10(PLOT(I))
      X2(I) = ALOG10(RATE(I))
      WRITE(4,26)I,T(I),X1(I),X2(I)
   26 FORMAT (1X,I2,2X,F9.7,2X,F9.7,2X,F9.7)
      SUMHRS = SUMHRS + HRS(I)
      SUMX1  = SUMX1  + X1(I)
      SUMX2  = SUMX2  + X2(I)
      SUMT   = SUMT   + T(I)
      SSX1   = SSX1   + X1(I)**2
      SSX2   = SSX2   + X2(I)**2
      SST    = SST + T(I)**2
      SUMX1T = SUMX1T + X1(I)*T(I)
      SUMX2T = SUMX2T + X2(I)*T(I)
      SMX1X2 = SMX1X2 + X1(I)*X2(I)
   30CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     DATA CHECK OPTION SELECTION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      PRINT 35,DATAFILE
   35 FORMAT(1X,"DO YOU WANT TO CHECK DATA AS IT IS READ FROM FILE ",A8," AND CONVERTED TO LOGARITHMS")
  103 INPUT,ANSWER(2)
      IF (ANSWER(2).EQ."NO") GO TO 104
      IF (ANSWER(2).EQ."YES") GO TO 104
      PRINT," ANSWER YES OR NO ONLY PLEASE"
      GO TO 103
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     PREDICTIVE ABILITY TEST OPTION SELECTION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
  104 PRINT 40
   40 FORMAT(1X,"DO YOU WANT A COMPARISON OF THE SHORTRANGE PREDICTIVE ABILITY OF THE TWO MODELS")
  105 INPUT,ANSWER(3)
      IF (ANSWER(3).EQ."NO") GO TO 106
      IF (ANSWER(3).EQ."YES") GO TO 203
      PRINT," ANSWER YES OR NO ONLY PLEASE"
      GO TO 105
  203 PRINT 42
   42 FORMAT(1X,"ENTER PREDICTION RANGE (CASE NUMBERS FOR FIRST AND LAST CASES)")
 1900 INPUT,ITRUNC,ITOEUP
      IF(NCASES-ITRUNC+1.LE.NCASES/2-2)GO TO 106
      PRINT 1904
 1904 FORMAT(1H ,'NUMBER OF CASES INPUT EXCEED ALLOWABLE AMOUNT--REENTER NUMBER OF CASES TO BE TRUNCATED')
      GO TO 1900
```

```
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     PROJECTION AND SENSITIVITY MATRIX OPTION SELECTION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
  106  PRINT 45
    45 FORMAT(1X,"DO YOU WANT PROJECTION AND SENSITIVITY MATRIX")
  107  INPUT,ANSWER(4)
       IF (ANSWER(4).EQ."NO") GO TO 108
       IF (ANSWER(4).EQ."YES") GO TO 108
       PRINT," ANSWER YES OR NO ONLY PLEASE"
       GO TO 107
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     BEGIN DATA CHECK OPTION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
  108  IF (ANSWER(2).EQ."NO") GO TO 109
PRINT 50,DATAFILE
    50 FORMAT(1H1,//,75("*"),/,5X,"INPUT DATA AS READ FROM FILE ",A8," AND CONVERTED TO LOGARITHMS",
&        /,75("*"))
       PRINT," LINE    DIRECT LABOR HOURS  * CUM PROD PLOT POINT * PRODUCTION RATE"
       PRINT," NUMBER  RATIONAL  LOGARITHM * RATIONAL  LOGARITHM * RATIONAL  LOGARITHM"
       DO 60 I=1,NCASES
       PRINT 55,LN(I),HRS(I),Y(I),PLOT(I),X1(I),RATE(I),X2(I)
    55 FORMAT(1X,1X,I3,5X,F8.2,2X,F9.7," * ",F8.2,2X,F9.7," * ",F8.2,2X,F9.7)
    60CONTINUE
       PRINT 65
    65 FORMAT (1X,75("*"))
109 CONTINUE
C********************************************************************************************
C
C     PART II - PEARSON CORRELATION COEFFICIENTS AND REGRESSION ANALYSIS
C
C********************************************************************************************
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT PEARSON CORRELATION COEFFICIENTS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
       RX1Y  = (SUMX1Y-SUMX1*SUMY/NCASES)/SQRT((SSX1-(SUMX1**2/NCASES))*(SSY-(SUMY**2/NCASES)))
       RX2Y  = (SUMX2Y-SUMX2*SUMY/NCASES)/SQRT((SSX2-(SUMX2**2/NCASES))*(SSY-(SUMY**2/NCASES)))
       RX1X2 = (SUMX1X2-SUMX1*SUMX2/NCASES)/SQRT((SSX1-(SUMX1**2/NCASES))*(SSX2-(SUMX2**2/NCASES)))
       RX1X1 = 1.0
       RX2X2 = 1.0
       RYY   = 1.0
       PRINT 71,RYY,RX1Y,RX2Y,RX1Y,RX1X1,RX1X2,RX2Y,RX1X2,RX2X2
    71 FORMAT(1X,///,1X,45("*"),/,4X,"PEARSON CORRELATION COEFFICIENTS ",
&      "MATRIX",/,1X,45("*"),//,6X,"*",5X,"Y",6X,"*",5X,"X1",5X,"*",5X,
&      "X2",/,1X,45("*"),/,2X,"Y",3X,3("* ",F10.7,1X),/,1X,45("*"),/,2X,
&      "X1",2X,3("* ",F10.7,1X),/,1X,45("*"),/,2X,"X2",2X,3("* ",F10.7,1X),////)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT THE REGRESSION RESULTS OF THE STANDARD LEARNING CURVE MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
       B1 =(SUMX1Y-((SUMX1*SUMY)/NCASES))/(SSX1-(SUMX1**2/NCASES))
       YBAR = SUMY/NCASES
       HRSBAR = SUMHRS/NCASES
       X1BAR = SUMX1/NCASES
```

```
      X2BAR = SUMX2/NCASES
      B0 = YBAR- B1*X1BAR
      AE0 = 10.**B0
IF(ANS(3).EQ."NO")PRINT 775
775 FORMAT(//1X,75("*"),/14X,"RESULTS OF STANDARD LEARNING CURVE MODEL")
IF(ANS(3).EQ."NO")GO TO 776
PRINT 75
   75 FORMAT(1X,75("*"),/,14X,"RESULTS OF THE STANDARD LEARNING",
&     " CURVE MODEL",/,1X,75("*"),/,1X,"CASE",3X,"OBSERVED",5X,"PREDICTED",
&     5X,"RESIDUAL",5X,"% DEVIATION")
776 DO 110 I=1,NCASES
      YHATL  = B0 + B1 * X1(I)
      RESIDL = Y(I) - YHATL
      SSEL1  = SSEL1 + RESIDL ** 2
      SSTOL1 = SSTOL1 + (Y(I) - YBAR) ** 2
      YHAT   = 10 ** YHATL
      RESID(I) = HRS(I) - YHAT
      PERCENT= (RESID(I)/ HRS(I)) * 100
      SSE1   = SSE1 + RESID(I)** 2
      SSTO1  = SSTO1 + (HRS(I) - HRSBAR) ** 2
WRITE("STDLEARN",20)YHAT,RESID(I)
20 FORMAT(F8.2,F8.2)
IF(ANS(3).EQ."NO")GO TO 110
      PRINT 80,I,HRS(I),YHAT,RESID(I),PERCENT
   80 FORMAT(1X,I3,4X,F8.2,6X,F8.2,5X,F8.2,7X,F6.2)
 110 CONTINUE
CLOSE(FILE='STDLEARN')
CALL SYSTEM("/SORT*** STDLEARN;STDCURVE;2R8{-1,-2",$2000)
DO 2770 I=1,NCA
READ('STDCURVE',*)YHAT,RESID(I)
SUMRESID=SUMRESID+RESID(I)**2
IF(I.GT.1)
RESIDIF=RESID(I)-RESID(I-1)
RESIDIF2=RESIDIF**2
RESIDSUM=RESIDSUM+RESIDIF2
ENDIF
2770 CONTINUE
DWSTAT=RESIDSUM/SUMRESID
SUMRESID=RESIDSUM=0
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT STATISTICS FOR THE STANDARD LEARNING CURVE MODEL
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2000 NDFD=NCASES-2
      THSRL = (SSTOL1 - SSEL1)
      THSEL = SSEL1 / NDFD
      SEE   = SQRT (THSEL)
      VARB0 = SEE / (1 / NCASES + X1BAR **2 / (SSX1 - (SUMX1 ** 2 / NCASES)))
      SEB0  = SQRT (VARB0)
      SEB1  = SEE / (SQRT(SSX1-(SUMX1)**2/NCASES)))
      RSQL1 = (SSTOL1 - SSEL1) / SSTOL1
      RSQA1 = (SSTO1- SSE1) / SSTO1
      FRATIO= THSRL / THSEL
      PLEARN= (10 ** (B1 * ALOG10(2.0))) * 100
```

```
      PRINT 81,B0,SEE0,AB0,B1,SEB1,RSQL1,SEE,TMSEL,TMSRL,FRATIO,NDFD,RSQA1,PLEARN,DWSTAT
   81 FORMAT(1X,75("*"),/,1X,"THE EQUATION FOR THIS MODEL IS: ",
&     "     THAT = B0 * X1 ** B1",/,1X,
&     "IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1)",
&     /,1X,"WHERE: LOG(B0) =",F8.5,4X,"STD ERROR =",F8.5,4X,"B0 =",F11.5,
&     /,13X,"B1 =",F8.5,4X,"STD ERROR =",F8.5,
&     /,1X,"SUMMARY STATISTICS:",/,1X,
&     "R SQUARED LOG   =",F7.5,10X,"STD ERROR EST =",F11.4,/,1X,
&     "MSE",13X,"=",F9.5,8X,"MSR",11X,"=",F9.5,/,1X,
&     "F RATIO",9X,"=",F9.4,8X,"D. F. (N/D)   = 1/",I3,/1X,
&     "R SQUARED ACTUAL=",F7.5,8X,"LEARNING FACTOR =",F9.5," PERCENT",
& /1X,"DURBIN-WATSON STATISTIC="F9.6
&     /,1X,75("*"))
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT THE REGRESSION RESULTS FOR THE REDUCED HRS VS RATE MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      B2 =(SUMX2T-((SUMX2*SUMT)/NCASES))/(SSX2-(SUMX2**2/NCASES))
      B0 = TBAR - B2 * X2BAR
AB0=10**B0
IF(ANS(3).EQ."YES")GO TO 3820
PRINT 820
820 FORMAT(//1X,75("*")/11X,"RESULTS OF REGRESSION ON PRODUCTION RATE VARIABLE ALONE")
GO TO 3860
3820 PRINT 82
   82 FORMAT(1X,75("*"),/,11X,"RESULTS OF REGRESSION ON PRODUCTION",
&     " RATE VARIABLE ALONE",/,1X,75("*"),/,1X,"CASE",3X,"OBSERVED",5X,
&     "PREDICTED",5X,"RESIDUAL",5X,"% DEVIATION")
3860 DO 111 I=1,NCASES
      THATL  = B0 + B2 * X2(I)
      RESIDL = T(I) - THATL
      SSEL2   = SSEL2 + RESIDL **2
      SSTOL2  = SSTOL2 + (T(I) - TBAR) ** 2
      THAT    = 10 ** THATL
      RESID(I) = HRS(I) - THAT
      PERCENT= (RESID(I)/ HRS(I)) * 100
      SSE2    = SSE2 + RESID(I)**2
      SSTO2   = SSTO2 + (HRS(I) - HRSBAR) ** 2
WRITE("REDHOURS",20)THAT,RESID(I)
IF(ANS(3).EQ."NO")GO TO 111
      PRINT 80,I,HRS(I),THAT,RESID(I),PERCENT
 111 CONTINUE
CLOSE(FILE='REDHOURS')
CALL SYSTEM('/SORT*** REDHOURS;REDCURVE;ZR0;-1,-2',&3340)
DO 3314 I=1,NCASES
READ('REDCURVE',*)THAT,RESID(I)
SUMRESID=SUMRESID+RESID(I)**2
IF(I.GT.1)
RESIDIF=RESID(I)-RESID(I-1)
RESIDIF2=RESIDIF**2
RESIDSUM=RESIDSUM+RESIDIF2
ENDIF
3314 CONTINUE
```

```
 DWSTAT=RESIDSUM/SUMRESID
 SUMRESID=RESIDSUM=0
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT STATISTICS FOR THE REDUCED HRS VS RATE MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
 3340 TMSRL=(SSTOL2-SSEL2)
       TMSEL = SSEL2 / NDFD
       SEE   = SQRT(TMSEL)
       VARB0 = SEE / (1 / NCASES + X2BAR ** 2 / (SSX2 - (SUMX2 ** 2 / NCASES)))
       SEB0  = SQRT (VARB0)
       SEB2  = SEE / (SQRT (SSX2 - (SUMX2 ** 2 / NCASES)))
       RSQL2 = (SSTOL2 - SSEL2) / SSTOL2
       RSQA2 = (SST02- SSE2) / SST02
       FRATIO= TMSRL / TMSEL
       PRINT 83,B0,SEB0,AB0,B2,SEB2,RSQL2,SEE,TMSEL,TMSRL,FRATIO,NDFD,RSQA2,DWSTAT
 83 FORMAT(1X75("*")/1X"THE EQUATION FOR THIS MODEL IS: "
&      "      THAT = B0 * X2 ** B2",/,1X
&      "IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B2 * LOG(X2)",
&      /,1X,"WHERE: LOG(B0) =",F8.5,4X,"STD ERROR =",F8.5,4X,"B0 =",F11.5,
&      /,13X,"B2 =",F8.5,4X,"STD ERROR =",F8.5,
&      /,1X,"SUMMARY STATISTICS:",/,1X,
&      "R SQUARED LOG   =",F7.5,16X,"STD ERROR EST =",F11.4,/,1X,
&      "MSE",13X,"=",F9.5,8X,"MSR",11X,"=",F9.5,/,1X,
&      "F RATIO",9X,"=",F9.4,8X,"D. F. (N/D)   = 1/",I3,/,1X,
& "R SQUARED ACTUAL="F7.5/1X"DURBIN-WATSON STATISTIC="F9.6/1X75("*"))
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT THE REGRESSION RESULTS FOR THE FULL MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
       DENOM = ((SSX1-X1BAR*SUMX1)*(SSX2-X2BAR*SUMX2) - (SMX1X2-X1BAR*SUMX2)**2)
       B1 =((SSX2-X2BAR*SUMX2)*(SUMX1Y-X1BAR*SUMY) -
&          (SMX1X2-X1BAR*SUMX2)*(SUMX2Y-X2BAR*SUMY))/DENOM
       B2 = ((SSX1-X1BAR*SUMX1) *(SUMX2Y-X2BAR*SUMY) -
&         (SMX1X2-X1BAR*SUMX2)*(SUMX1Y-X1BAR*SUMY))/DENOM
       B0 = YBAR-B1*X1BAR-B2*X2BAR
       AB0 = 10.**B0
 IF(ANS(3).EQ."YES")GO TO 4320
 PRINT 840
 840 FORMAT(//1X,75("*")/6X,"RESULTS OF COMBINED CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL")
 GO TO 4360
 4320 PRINT 84
    84 FORMAT(1X,75("*"),/,6X,"RESULTS OF COMBINED CUMULATIVE PRODUCTION",
&       " AND PRODUCTION RATE MODEL",/,1X,75("*"),/,1X,"CASE",3X,"OBSERVED",5X,
&       "PREDICTED",5X,"RESIDUAL",5X,"% DEVIATION")
 4360 DO 112 I=1,NCASES
        THATL = B0 + B1 * X1(I) + B2 * X2(I)
        RESIDL= Y(I) - THATL
        SSEL  = SSEL + RESIDL ** 2
        SSTOL = SSTOL + (Y(I) - YBAR) ** 2
        THAT  = 10 ** THATL
        RESID(I)= HRS(I) - THAT
        PERCENT= (RESID(I)/ HRS(I)) * 100
        SSE   = SSE + RESID(I)** 2
```

```
      SSTO  = SSTO + (HRS(I) - HRSBAR) ** 2
WRITE("FULLMODL",20)THAT,RESID(I)
IF(ANS(3).EQ."NO")GO TO 112
      PRINT 60,I,HRS(I),THAT,RESID(I),PERCENT
 112 CONTINUE
CLOSE(FILE='FULLMODL')
CALL SYSTEM('/SORT*** FULLMODL;FULCURVE;2R0;-1,-2',$3890)
DO 3664 I=1,NCASES
READ('FULCURVE',*)THAT,RESID(I)
SUMRESID=SUMRESID+RESID(I)**2
IF(I.GT.1)
RESIDIF=RESID(I)-RESID(I-1)
RESIDIF2=RESIDIF**2
RESIDSUM=RESIDSUM+RESIDIF2
ENDIF
3664 CONTINUE
DWSTAT=RESIDSUM/SUMRESID
SUMRESID=RESIDSUM=0
C     CALCULATE AND PRINT STATISTICS FOR THE FULL MODEL
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3890 NDFD=NCASES-3
      TMSRL = (SSTOL - SSEL) / 2
      TMSEL = SSEL / NDFD
      SEE   = SQRT(TMSEL)
      ZVAL  = NCASES*(SSX1 * SSX2 - SMX1X2 ** 2) - SUMX1*(SUMX1 * SSX2 -
&              SMX1X2 * SUMX2) + SUMX2*(SUMX1 * SMX1X2 - SSX1 * SUMX2)
      AVAL  = (SSX1 * SSX2 - SMX1X2 ** 2) / ZVAL
      VARB0 = TMSEL * AVAL
      SEB0  = SQRT (VARB0)
      SEB1  = SQRT((TMSEL * (SSX2 - X2BAR * SUMX2)) / DENOM)
      SEB2  = SQRT((TMSEL * (SSX1 - X1BAR * SUMX1)) / DENOM)
      RSQL  = (SSTOL - SSEL) / SSTOL
      RSQA  = (SSTO - SSE) / SSTO
      FRATIO= TMSRL /TMSEL
      FB1   = (RSQL - RSQL2) / ((1 - RSQL) / (NCASES - 3))
      FB2   = (RSQL - RSQL1) / ((1 - RSQL) / (NCASES - 3))
      PRINT 85,B0,SEB0,AB0,B1,SEB1,FB1,B2,SEB2,FB2,RSQL,SEE,TMSEL,TMSRL,FRATIO,NDFD,RSQA,DWSTAT
   85 FORMAT(1X,75("*"),/,1X,"THE EQUATION FOR THIS MODEL IS: ",
&     "     THAT = B0 * X1 ** B1 * X2 **B2",/,1X,
&     "IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1) + B2 * LOG(X2)",
&     /,1X,"WHERE: LOG(B0) =",F8.5,4X,"STD ERROR =",F8.5,4X,"B0 =",F11.5,
&     /,13X,"B1 =",F8.5,4X,"STD ERROR =",F8.5,4X,"F* =",F10.4,/,
&     13X,"B2 =",F8.5,4X,"STD ERROR =",F8.5,4X,"F* =",F10.4,/,1X,
&     "SUMMARY STATISTICS:",/,1X,"R SQUARED LOG   =",F7.5,10X,
&     "STD ERROR EST =",F11.4,/,1X,"MSE",13X,"=",F9.5,8X,"MSR",11X,"=",F9.5,/,1X,
&     "F RATIO",9X,"=",F9.4,8X,"D. F. (N/D)   = 2/",I3,/,1X,
& "R SQUARED ACTUAL="F7.5/1X"DURBIN-WATSON STATISTIC="F9.6/1X75("*"))
C**************************************************************************************
C
C     PART III - PREDICTIVE ABILITY TEST OPTION
C
C**************************************************************************************
```

```
      IF (ANSWER(3).EQ."NO") GO TO 116
IF(ANS(3).EQ."NO")PRINT 4173
ITRUNC=NCASES-ITRUNC+1
ITOEUP=NCASES-ITOEUP+1
DO 113 I=ITOEUP,ITRUNC
      ITEST = NCASES + 1 - I
4173 FORMAT(//)
IF(ANS(3).EQ."NO")GO TO 4980
      PRINT 86,ITEST,HRS(ITEST)
   86 FORMAT(1X,116("*"),/,1X,"*",37X,"SHORTRANGE PREDICTIVE ABILITY ",
&     "COMPARISON",37X,"*",/,1X,"*",16X,
&     "THE DATA PRESENTED BELOW IS FOR CASE #",I3," WHICH HAS AN OBSERVED",
&     " VALUE OF:",F9.2,16X,"*",/,
&     1X,116("*"),/1X,"*",3X,"#",3X,"*",9X,"REDUCED (LEARNING CURVE) ",
&     "MODEL",6X,"**",3X,"FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) ",
&     "MODEL",2X,"*",/,1X,"*"," CASES ",100("*"),/,1X,"*  USED * ",
&     "PREDICTION * % DEVIATION *  EST B0  * EST B1  ** ",
&     "PREDICTION * % DEVIATION *  EST B0  * EST B1  * EST B2  *",
&     /,1X,116("*"))
4980 DO 114 J=1,ITRUNC
      ICASES = ITEST - J
      SUMT   = 0
      SUMX1  = 0
      SUMX2  = 0
      SSX1   = 0
      SSX2   = 0
      SUMX1T = 0
      SUMX2T = 0
      SMX1X2 = 0
      DO 115 K=1,ICASES
       SUMT   = SUMT + T(K)
       SUMX1  = SUMX1 + X1(K)
       SUMX2  = SUMX2 + X2(K)
       SSX1   = SSX1 + X1(K) ** 2
       SSX2   = SSX2 + X2(K) ** 2
       SUMX1T = SUMX1T + X1(K) * T(K)
       SUMX2T = SUMX2T + X2(K) * T(K)
       SMX1X2 = SMX1X2 + X1(K) * X2(K)
  115 CONTINUE
       ICOUNTA = ICOUNTA + 1
       TBAR  = SUMT / ICASES
       X1BAR = SUMX1 / ICASES
       X2BAR = SUMX2 / ICASES
       B1R   = (SUMX1T - ((SUMX1 * SUMT) / ICASES)) / (SSX1 - (SUMX1 ** 2 / ICASES))
       B0R   = TBAR - B1R * X1BAR
       AS0R  = 10 ** B0R
       THATR = 10 ** (B0R + B1R * X1(ITEST))
       DEVR    = HRS(ITEST) - THATR
       ADEVR(ICOUNTA) = ABS(DEVR)
       SUMADEVR = SUMADEVR + ADEVR(ICOUNTA)
       PDEVR   = 100 * DEVR/HRS(ITEST)
       APDEVR = ABS(PDEVR)
```

```
      IF (APDEVR.GT.10.0) GO TO 201
      ICOUNTGR = ICOUNTGR + 1
      IF (APDEVR.GT.5.0) GO TO 201
      ICOUNTER = ICOUNTER + 1
  201 DENOM = ((SSX1-X1BAR*SUMX1)*(SSX2-X2BAR*SUMX2) - (SMX1X2-X1BAR*SUMX2)**2)
      B1F   = ((SSX2-X2BAR*SUMX2)*(SUMX1T-X1BAR*SUMT) -
&            (SMX1X2-X1BAR*SUMX2)*(SUMX2T-X2BAR*SUMT))/DENOM
      B2F   = ((SSX1-X1BAR*SUMX1)*(SUMX2T-X2BAR*SUMT) -
&            (SMX1X2-X1BAR*SUMX2)*(SUMX1T-X1BAR*SUMT))/DENOM
      B0F   = TBAR - B1F * X1BAR - B2F * X2BAR
      AB0F  = 10 ** B0F
      THATF = 10  ** (B0F + B1F * X1(ITEST) + B2F * X2(ITEST))
      DEVF  = HRS(ITEST) - THATF
      ADEVF(ICOUNTA) = ABS(DEVF)
      SUMADEVF = SUMADEVF + ADEVF(ICOUNTA)
      PDEVF = 100 * DEVF/HRS(ITEST)
      APDEVF = ABS(PDEVF)
      IF (APDEVF.GT.10.0) GO TO 202
      ICOUNTGF = ICOUNTGF + 1
      IF (APDEVF.GT.5.0) GO TO 202
      ICOUNTEF = ICOUNTEF + 1
 202 IF(ANS(3).EQ."NO")GO TO 114
     PRINT 87,ICASES,THATR,PDEVR,AB0R,B1R,THATF,PDEVF,AB0F,B1F,B2F
   87 FORMAT(1X,"*",2X,I3,2X,"*",1X,F9.2,2X,"*",3X,F6.2,4X,"*",F9.2,1X,
&     "*",F8.5,1X,"**",1X,F9.2,2X,"*",3X,F6.2,4X,"*",F9.2,1X,"*",F8.5,1X,
&     "*",F8.5,1X,"*")
 114 CONTINUE
IF(ANS(3).EQ."NO")GO TO 5590
      PRINT 88
   88 FORMAT(1X,116("*"),//////)
5590 COUNT=COUNT+1.
      FLAG1 = COUNT / 2.0
      FLAG2 = FLAG1 - INT(FLAG1)
      IF (FLAG2.NE.0.0) GO TO 113
 113 CONTINUE
      AVGADEVR = SUMADEVR / ICOUNTA
      AVGADEVF = SUMADEVF / ICOUNTA
      DO 119 I =1,ICOUNTA
       SSDEVR  = SSDEVR + (ADEVR(I) - AVGADEVR)**2
       SSDEVF  = SSDEVF + (ADEVF(I) - AVGADEVF)**2
 119 CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C     CALCULATE AND PRINT RESULTS SUMMARY FOR PREDICTIVE ABILITY TESTS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
       VARADEVR = SSDEVR / (ICOUNTA - 1)
       VARADEVF = SSDEVF / (ICOUNTA - 1)
       TESTSTAT = (AVGADEVR-AVGADEVF)/SQRT((VARADEVR/ICOUNTA)+(VARADEVF/ICOUNTA))
       PCENTER = 100 * ICOUNTER / ICOUNTA
       PCENTGR = 100 * ICOUNTGR / ICOUNTA
       PCENTEF = 100 * ICOUNTEF / ICOUNTA
       PCENTGF = 100 * ICOUNTGF / ICOUNTA
       PRINT 95,AVGADEVR,AVGADEVF,VARADEVR,VARADEVF,TESTSTAT,ICOUNTA,
```

```
         ICOUNTA,ICOUNTER,ICOUNTEF,PCENTER,PCENTEF,ICOUNTCR,ICOUNTCF,PCENTCR,
         PCENTCF
      95 FORMAT(1X,67("*"),/,1X,"*",10X,"SUMMARY OF PREDICTIVE ABILITY TESTS",
         " RESULTS",12X,"*",/,1X,67("*"),/,1X,"*",9X,"ITEMS OF INTEREST",8X,
         "* REDUCED MODEL *  FULL MODEL  *",/,1X,67("*"),/,1X,"* AVERAGE ",
         "ABSOLUTE DEVIATION",7X,"*",3X,F9.2,3X,"*",2X,F9.2,3X,"*",/,1X,
         "* VARIANCE OF ABSOLUTE DEVIATIONS",2X,"*",1X,F11.2,3X,"*",F11.2,3X,
         "*",/,1X,"* TEST STATISTIC (SEE NOTE)",8X,"*",6X,"---",6X,"*",2X,
         F9.2,3X,"*",/,1X,"* TOTAL NUMBER OF TEST SITUATIONS  *",6X,I3,6X,"*",
         5X,I3,6X,"*",/,1X,"* NUMBER OF PREDICTIONS WITHIN 5%  *",6X,I3,6X,
         "*",5X,I3,6X,"*",/,1X,"* PERCENT OF PREDICTIONS WITHIN 5% *",6X,F4.0,
         5X,"*",5X,F4.0,5X,"*",/,1X,"* NUMBER OF PREDICTIONS WITHIN 10% *",
         6X,I3,6X,"*",5X,I3,6X,"*",/,1X,"* PERCENT OF PREDICTIONS WITHIN 10%*",
         6X,F4.0,5X,"*",5X,F4.0,5X,"*",/,1X,67("*"),/,1X,"NOTE: IN TESTING FOR ",
         "STATISTICAL SIGNIFICANCE USE STUDENT'S T DISTRIBUTION",/,1X
         "IF THE NUMBER OF TEST SITUATIONS ARE LESS THAN 60; OTHERWISE ",
         "USE STANDARD",/,1X,"NORMAL DISTRIBUTION.  IN EITHER CASE THIS IS ",
         "A ONE TAILED TEST.  IF",/,1X,"THE TEST STATISTIC IS GREATER THAN ",
         "THE CRITICAL STATISTIC ONE MAY",/,1X,"CONCLUDE THAT THE AVERAGE ",
         "ABSOLUTE DEVIATION OBTAINED WITH THE FULL",/,1X,"MODEL IS ",
         "SIGNIFICANTLY LESS THAN THAT OBTAINED WITH THE REDUCED MODEL.")
 PRINT,"FILES LOGFILE,STDLEARN,REDHOURS,AND FULLMODL WRITTEN."
C************************************************************************************
C
C     PART IV - PROJECTION AND SENSITIVITY MATRIX OPTION
C
C************************************************************************************
 116  IF (ANSWER(4).EQ."NO") GO TO 125
        ADDPLOT = PLOT(NCASES)
       DO 117 I=1,100
        ADDPLOT = ADDPLOT + .01 * PLOT(NCASES)
        NEWPLOT(I) = INT(ADDPLOT)
        ADDRATE = .60 * RATE(NCASES)
       DO 118 J=1,9
        ADDRATE = ADDRATE + .1 * RATE(NCASES)
        PRORATE(J) = ADDRATE
        FHRS(I,J)  = A00 * NEWPLOT(I)**B1 * PRORATE(J)**B2
 118 CONTINUE
 117 CONTINUE
        ISTART = 1
        ISTOP  = 50
       DO 120 K=1,2
        PRINT 89,(PRORATE(J),J=1,9)
     89 FORMAT(1X,113("*"),/,1X,"*",39X,"PROJECTION AND SENSITIVITY MATRIX",
        39X,"*",/,1X,113("*"),/,1X,"*  PROJECTED *",36X,"PROJECTED PRODUCTION",
        " RATES",36X,"*",/,1X,"* CUMULATIVE *",99("*"),/,1X,"*    UNITS   *",
        9(F8.2,2X,"*"),/,1X,113("*"))
       DO 121 I=ISTART,ISTOP
        PRINT 90,NEWPLOT(I),(FHRS(I,J),J=1,9)
     90 FORMAT(1X,"*",3X,I6,3X,"*",9(1X,F8.1,1X,"*"))
 121 CONTINUE
        PRINT 91
```

```
    91 FORMAT(1X,113("*"))
       PRINT92
    92 FORMAT(1X,"NOTE: 1.  PROJECTED VALUES FOR DIRECT LABOR HOURS MAY ",
      "BE READ FROM THE ABOVE MATRIX BY MATCHING A GIVEN PRODUCTION",/,1X,
      "RATE WITH A GIVEN NUMBER OF CUMULATIVE UNITS AND READING THE ",
      "VALUE FOR DIRECT LABOR HOURS FOUND AT THE INTERSECTION",/,1X,
      "OF THE CORRESPONDING ROW AND COLUMN.  FORECASTING MODEL IS THE ",
      "CUMULATIVE PRODUCTION & PRODUCTION RATE MODEL.",/,7X,"2.  PROJECT",
      "ION INTERVAL FOR CUMULATIVE UNITS IS 1% OF THE LAST OBSERVED VALUE",
      " OF CUMULATIVE UNITS.",/,7X,"3.  PROJECTION VALUES FOR PRODUCTION ",
      "RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF ",
      "THE",/,1X,"LAST OBSERVED VALUE OF PRODUCTION RATE.")
       ISTART = 51
       ISTOP  = 10
   120 CONTINUE
   125 STOP1
       END
```

Sample PRODRATE Output

This next section provides a sample output of the abbreviated and full format options using simulated data. The data base was developed by Stevens and Thomerson (15:127) to demonstrate how the PRODRATE program works. It should be noted the data were developed to demonstrate superior results for the full model. The program instructions are presented first, then the abbreviated format followed by the full format. This comparison of the optional formats will, hopefully, demonstrate the value of the abbreviated option.

****

PRODRATE INSTRUCTIONS

****

THIS PROGRAM IS DESIGNED TO EVALUATE THE VARIATION IN DIRECT LABOR REQUIREMENTS AS A FUNCTION OF CUMULATIVE PRODUCTION AND PRODUCTION RATE. IN ADDITION, THE ANALYST MAY COMPARE THE RESULTS OBTAINED FROM THE STANDARD LEARNING CURVE WITH THE RESULTS OBTAINED FROM THE CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL. THE COST MODELS USED IN THIS PROGRAM ARE:

1. REDUCED MODEL (STANDARD LEARNING CURVE MODEL)

   Y = B0 * (X1 ** B1) * (10 ** E)

2. FULL MODEL (CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL)

   Y = B0 * (X1 ** B1) * (X2 ** B2) * (10 ** E)

WHERE: Y — IS THE DIRECT LABOR REQUIREMENTS
X1 — IS THE CUMULATIVE PRODUCTION PLOT POINT
X2 — IS THE PRODUCTION RATE PROXY(E.G. EQUIVALENT UNITS PER MONTH)
E — REPRESENTS THE ERROR TERM
B0, B1, AND B2 — ARE PARAMETERS DETERMINED BY REGRESSION

DATA ARE INPUT BY READING FROM ANY PROPERLY FORMATTED DATA FILE. YOUR DATA FILE SHOULD BE SAVED TO ANY PERMANENT FILENAME. YOU WILL BE ASK TO INPUT THE NAME OF YOUR DATA FILE AT THE APPROPRIATE STEP IN THE PROGRAM. THE NAME OF YOUR DATA FILE CAN NOT EXCEED 8 CHARACTERS. THE FIRST LINE OF THE DATA FILE MUST CONTAIN A LINE NUMBER AND THE NUMBER OF CASES TO BE READ. THE DATA IS THEN ENTERED ONE CASE PER LINE IN THE FOLLOWING ORDER: LINE NUMBER, OBSERVED DIRECT LABOR REQUIREMENT (Y), CUMULATIVE PRODUCTION PLOT POINT (X1), AND PRODUCTION RATE PROXY (X2). THE PROGRAM USES A FREE FIELD READ FORMAT; THEREFORE, EACH VARIABLE MUST BE SEPARATED BY AT LEAST ONE SPACE (OR OTHER DELIMITER) BUT NO OTHER SPECIAL FORMAT IS REQUIRED. AN EXAMPLE OF A DATA FILE WITH 5 CASES IS PRESENTED BELOW:

```
100   5
101   100    9.5    9.5
102    90   30     20.5
103    80   55     25
104    75   82     27
105    71  113     31
```

ONE ADVANTAGE OF THIS PROGRAM IS THAT THE RESULTS OBTAINED WILL BE IN THE SAME UNITS AND FORM AS THE INPUT DATA. FOR EXAMPLE, IF YOU ARE WORKING IN DIRECT LABOR HOURS PER MONTH AND EQUIVALENT UNITS, THE RESULTS WILL BE IN TERMS OF THESE UNITS. ALSO, IF YOU WISH TO USE A CUMULATIVE AVERAGE APPROACH, ALL YOU NEED DO IS AGGREGATE THE DATA BASE IN THAT MANNER.

THE PROGRAM BEGINS BY TRANSFORMING THE INPUT DATA TO COMMON LOGARITHMS. LOG LINEAR REGRESSION IS THEN PERFORMED AS FOLLOWS: Y REGRESSED ON X1, Y REGRESSED ON X2, AND FINALLY Y REGRESSED ON BOTH X1 AND X2. OBSERVED DIRECT LABOR REQUIREMENTS, PREDICTED DIRECT LABOR REQUIREMENTS, AND RESIDUALS ARE PRINTED IN ORIGINAL (UNTRANSFORMED) FORM FOR EACH REGRESSION SITUATION. IN ADDITION, SUMMARY STATISTICS ARE PRINTED FOR EACH MODEL. THE SUMMARY STATISTICS INCLUDE TWO COEFFICIENTS OF DETERMINATION R SQUARED LOG AND R SQUARED ACTUAL. THE R SQUARED LOG REPRESENTS THE GOODNESS OF FIT OF THE MODEL TO THE TRANSFORMED DATA (LOG FORM). THE R SQUARED ACTUAL, ON THE OTHER HAND, IS COMPUTED USING THE UNTRANSFORMED RESIDUALS, AND IS REPRESENTATIVE OF HOW WELL THE MODEL FITS THE UNTRANSFORMED DATA. THE DURBIN-WATSON STATISTIC IS CALCULATED FOR ASSESSMENT OF AUTOCORRELATION OF THE RESIDUALS.

SEVERAL OPTIONS ARE AVAILABLE WITHIN THIS PROGRAM AND CAN BE SELECTED BY APPROPRIATE ANSWERS TO THE FOLLOWING QUESTIONS:

1. DO YOU WANT TO CHECK DATA AS IT IS READ FROM FILE .... AND CONVERTED TO LOGARITHMS?

YES - WILL CAUSE THE PRINTING OF A LISTING OF THE RATIONAL INPUT DATA AND THE ASSOCIATED LOGARITHMIC VALUES.

NO - SUPPRESSES THIS OPTION.

2. COMPLETE PRINTOUT?

YES - WILL CAUSE OUTPUT TO BE PRINTED IN FULL FORMAT AS DESCRIBED ABOVE.
NO - WILL DELETE THE LISTING OF OBSERVED, PREDICTED, AND RESIDUAL VALUES BETWEEN TABLES OF SUMMARY STATISTICS. IT WILL ALSO DELETE LISTING OF INDIVIDUAL MATRICES FOR THE SHORTRANGE PREDICTIVE ABILITY OPTION;I.E., ONLY THE SUMMARY TABLE WILL BE LISTED.

3. DO YOU WANT A COMPARISON OF THE SHORTRANGE PREDICTIVE ABILITY OF THE TWO MODELS?

YES - WILL CAUSE THE PREDICTIVE ABILITY TEST OPTION TO BE ACTIVATED AND THE USER WILL BE TOLD: 'ENTER PREDICTION RANGE (CASE NUMBERS FOR FIRST AND LAST CASES).' THE USER SHOULD ENTER THE NUMBER OF THE FIRST CASE TO BE PREDICTED FOLLOWED BY THE LAST CASE TO BE PREDICTED, SEPARATED BY A COMMA. THE CASE NUMBERS MUST BE INTEGER VALUES GREATER THAN OR EQUAL TO 2. THE PREDICTIVE ABILITY TEST SIMULATES FUTURE PREDICTIONS BY PERFORMING A STEPWISE TRUNCATION OF THE HISTORICAL DATA. FOR THIS REASON, AN UPPER LIMITATION ON THE NUMBER OF CASES TRUNCATED WOULD BE: ((TOTAL NUMBER OF CASES IN DATA FILE) / 2) - 2 FOR EXAMPLE, IF YOUR DATA FILE CONTAINS 50 CASES, YOUR UPPER LIMIT WOULD BE 23 CASES. THIS, OF COURSE, REPRESENTS ONLY THE MAXIMUM NUMBER OF CASES THAT COULD BE TRUNCATED. IN PRACTICE YOU MAY WANT TO TRUNCATE ONLY A SMALL NUMBER OF CASES. THUS, IF YOUR DATA IS COLLECTED IN MONTHLY INTERVALS, YOU CAN LOOK AT THE PREDICTIVE ABILITY OF THE FULL AND REDUCED MODELS FOR AN 18 MONTH TIME SPAN BY SPECIFYING AN 18 CASE RANGE. IF YOUR DATA IS COLLECTED IN QUARTERS, YOU CAN LOOK AT THE PREDICTIVE ABILITY OF BOTH MODELS FOR AN 18 MONTH TIME SPAN BY SPECIFYING '6'. AFTER ALL PREDICTIVE ABILITY TEST SITUATIONS ARE PRINTED, THE PROGRAM PRINTS A SUMMARY OF THE TEST RESULTS.

NO - SUPPRESSES THIS OPTION.

4. DO YOU WANT PROJECTION AND SENSITIVITY MATRIX?

YES - WILL CAUSE PRINTING OF PROJECTION AND SENSITIVITY MATRIX. THIS MATRIX PRESENTS PROJECTED DIRECT LABOR REQUIREMENTS FOR SELECTED PAIRS OF CUMULATIVE PRODUCTION PLOT POINTS AND PRODUCTION RATES. THE PROJECTION INTERVAL FOR THE CUMULATIVE PRODUCTION PLOT POINT IS 1% OF THE LAST OBSERVED VALUE. THE PROJECTION VALUES FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF THE LAST OBSERVED VALUE OF PRODUCTION RATE.

NO -SUPPRESSES THIS OPTION.

SPECIAL NOTE THE PREDICTED DIRECT LABOR REQUIREMENTS AND RESIDUALS FOR EACH MODEL ARE STORED IN SEPARATE FILES. THE VALUES FOR THE STANDARD LEARNING CURVE MODEL ARE STORED IN A FILE CALLED 'STDLEARN'; THE VALUES FOR THE PRODUCTION RATE VARIABLE ALONE MODEL IN THE FILE 'REDHOURS'; AND THE VALUES FOR THE COMBINED CUM. PRODUCTION AND PRODUCTION RATE MODEL IN THE FILE 'FULLMODL'. USERS MAY ACCESS THESE FILES FOR RESIDUAL ANALYSIS BY OTHER COPPER IMPACT STATISTICAL PROGRAMS, IF DESIRED.

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***********************************************
  PEARSON CORRELATION COEFFICIENTS MATRIX
***********************************************

     *     Y      *     X1     *     X2
***********************************************
 Y   *  1.0000000 * -0.9955710 * -0.9841432
***********************************************
 X1  * -0.9955710 *  1.0000000 *  0.9964648
***********************************************
 X2  * -0.9841432 *  0.9964648 *  1.0000000
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******************************************************************************
            RESULTS OF STANDARD LEARNING CURVE MODEL
******************************************************************************
THE EQUATION FOR THIS MODEL IS:        YHAT = B0 * X1 ** B1
IN LOG FORM THIS MODEL BECOMES: LOG(YHAT) = LOG(B0) + B1 * LOG(X1)
WHERE: LOG(B0) = 3.49572    STD ERROR = 0.13455    B0 = 3131.24884
            B1 =-0.28262    STD ERROR = 0.00433
SUMMARY STATISTICS:
R SQUARED LOG   =0.99115          STD ERROR EST =     0.0164
MSE             =  0.00027        MSR           =  1.14390
F RATIO         =4255.4005        D. F. (N/D)   = 1/ 38
R SQUARED ACTUAL=0.98881        LEARNING FACTOR = 82.20945 PERCENT
DURBIN-WATSON STATISTIC= 0.327753
******************************************************************************
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******************************************************************************
         RESULTS OF REGRESSION ON PRODUCTION RATE VARIABLE ALONE
******************************************************************************
THE EQUATION FOR THIS MODEL IS: "      YHAT = B0 * X2 ** B2
IN LOG FORM THIS MODEL BECOMES: LOG(YHAT) = LOG(B0) + B2 * LOG(X2)
WHERE: LOG(B0) = 3.25379    STD ERROR = 0.23957    B0 = 1793.86990
            B2 =-0.74392    STD ERROR = 0.02175
SUMMARY STATISTICS:
R SQUARED LOG   =0.96854          STD ERROR EST =     0.0309
MSE             =  0.00096        MSR           =  1.11700
F RATIO         =1165.7958        D. F. (N/D)   = 1/ 38
R SQUARED ACTUAL=0.95679
DURBIN-WATSON STATISTIC= 0.277285
******************************************************************************
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************************************************************************
     RESULTS OF COMBINED CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL
************************************************************************
THE EQUATION FOR THIS MODEL IS:      YHAT = B0 * X1 ** B1 * X2 **B2
IN LOG FORM THIS MODEL BECOMES: LOG(YHAT) = LOG(B0) + B1 * LOG(X1) + B2 * LOG(X2)
WHERE: LOG(B0) = 3.75380    STD ERROR = 0.00116    B0 = 5672.84640
           B1 =-0.59957    STD ERROR = 0.00134    F* =68532.2109
           B2 = 0.84696    STD ERROR = 0.00356    F* =56384.9604
SUMMARY STATISTICS:
R SQUARED LOG    =0.99999         STD ERROR EST =     0.0004
MSE              =  0.00000       MSR           =  0.57705
F RATIO          =7968.2012       D. F. (N/D)   = 2/ 37
R SQUARED ACTUAL=1.00000
DURBIN-WATSON STATISTIC= 2.380320
************************************************************************
```

SUMMARY OF PREDICTIVE ABILITY TESTS RESULTS

ITEMS OF INTEREST	REDUCED MODEL	FULL MODEL
AVERAGE ABSOLUTE DEVIATION	3.84	0.16
VARIANCE OF ABSOLUTE DEVIATIONS	16.60	0.01
TEST STATISTIC (SEE NOTE)	---	13.58
TOTAL NUMBER OF TEST SITUATIONS	144	144
NUMBER OF PREDICTIONS WITHIN 5%	138	144
PERCENT OF PREDICTIONS WITHIN 5%	95.	100.
NUMBER OF PREDICTIONS WITHIN 10%	144	144
PERCENT OF PREDICTIONS WITHIN 10%	100.	100.

NOTE: IN TESTING FOR STATISTICAL SIGNIFICANCE USE STUDENT'S T DISTRIBUTION IF THE NUMBER OF TEST SITUATIONS ARE LESS THAN 40; OTHERWISE USE STANDARD NORMAL DISTRIBUTION. IN EITHER CASE THIS IS A ONE TAILED TEST. IF THE TEST STATISTIC IS GREATER THAN THE CRITICAL STATISTIC ONE MAY CONCLUDE THAT THE AVERAGE ABSOLUTE DEVIATION OBTAINED WITH THE FULL MODEL IS SIGNIFICANTLY LESS THAN THAT OBTAINED WITH THE REDUCED MODEL.

FILES LOGFILE,STDLEARN,REDHOURS,AND FULLMODL WRITTEN.

INPUT DATA AS READ FROM FILE TESTDATA AND CONVERTED TO LOGARITHMS

LINE NUMBER	DIRECT LABOR HOURS RATIONAL	DIRECT LABOR HOURS LOGARITHM	CUM PROD PLOT POINT RATIONAL	CUM PROD PLOT POINT LOGARITHM	PRODUCTION RATE RATIONAL	PRODUCTION RATE LOGARITHM
100	1088.00	3.0366289	50.00	1.6989700	2.27	0.3560259
110	841.00	2.9247155	175.00	2.2430381	3.85	0.5854607
120	641.00	2.8068580	313.00	2.4955443	4.45	0.6483600
130	560.00	2.7481880	454.00	2.6570559	4.94	0.6937269
140	493.00	2.6928469	626.00	2.7965743	5.33	0.7267272
150	462.00	2.6646420	795.00	2.9003671	5.85	0.7671559
160	437.00	2.6404814	1005.00	3.0021661	6.47	0.8109043
170	404.00	2.6063814	1206.00	3.0813473	6.71	0.8267225
180	368.00	2.5658478	1495.00	3.1746412	7.00	0.8450980
190	347.00	2.5403295	1775.00	3.2491983	7.37	0.8674675
200	330.00	2.5185139	2092.00	3.3205417	7.79	0.8915375
210	320.00	2.5051500	2421.00	3.3839948	8.33	0.9206450
220	317.00	2.5010593	2769.00	3.4423229	9.09	0.9585639
230	313.00	2.4955443	3176.00	3.5018805	9.86	0.9938769
240	309.00	2.4899585	3557.00	3.5510839	10.51	1.0216027
250	304.00	2.4828736	3976.00	3.5994464	11.17	1.0480532
260	298.00	2.4742163	4452.00	3.6485552	11.80	1.0718820
270	290.00	2.4623980	4964.00	3.6958318	12.37	1.0923697
280	284.00	2.4533183	5458.00	3.7370335	12.87	1.1095785
290	278.00	2.4440448	5959.00	3.7751734	13.38	1.1264561
300	270.00	2.4313638	6461.00	3.8102997	13.65	1.1351327
310	263.00	2.4199557	6972.00	3.8433574	13.98	1.1455072
320	256.00	2.4082400	7491.00	3.8745398	14.23	1.1532049
330	250.00	2.3979400	8080.00	3.9074114	14.65	1.1658376
340	245.00	2.3891661	8650.00	3.9370161	14.98	1.1755118
350	239.00	2.3783979	9248.00	3.9660478	15.29	1.1844075
360	235.00	2.3710679	9848.00	3.9933480	15.65	1.1945143
370	232.00	2.3654880	10450.00	4.0191163	16.04	1.2052044
380	228.00	2.3579348	11031.00	4.0426149	16.35	1.2135178
390	224.00	2.3502480	11626.00	4.0654303	16.66	1.2216750
400	221.00	2.3443923	12227.00	4.0873199	16.97	1.2296818
410	218.00	2.3384565	12838.00	4.1084974	17.27	1.2372923
420	216.00	2.3344537	13349.00	4.1254487	17.56	1.2445245
430	214.00	2.3304138	13849.00	4.1414184	17.81	1.2506639
440	211.00	2.3242824	14337.00	4.1564583	18.01	1.2555137
450	209.00	2.3201463	14866.00	4.1721941	18.22	1.2605484
460	206.00	2.3138672	15454.00	4.1890439	18.41	1.2650538
470	203.00	2.3074960	16048.00	4.2054209	18.58	1.2690457
480	200.00	2.3010300	16654.00	4.2215166	18.78	1.2736956
490	198.00	2.2966652	17172.00	4.2348208	18.94	1.2773800

PEARSON CORRELATION COEFFICIENTS MATRIX

	Y	X1	X2
Y	1.0000000	-0.9955710	-0.9841432
X1	-0.9955710	1.0000000	0.9964648
X2	-0.9841432	0.9964648	1.0000000

RESULTS OF THE STANDARD LEARNING CURVE MODEL

CASE	OBSERVED	PREDICTED	RESIDUAL	% DEVIATION
1	1088.00	1036.45	51.55	4.74
2	803.00	727.41	75.59	9.41
3	641.00	617.19	23.81	3.71
4	560.00	555.61	4.39	0.78
5	493.00	507.39	-14.39	-2.92
6	462.00	474.25	-12.25	-2.65
7	437.00	443.05	-6.05	-1.57
8	404.00	421.56	-17.56	-4.35
9	368.00	396.72	-28.72	-7.81
10	347.00	377.93	-30.93	-8.91
11	330.00	368.78	-38.78	-9.33
12	320.00	346.19	-26.19	-8.19
13	317.00	333.36	-16.36	-5.14
14	313.00	320.63	-7.63	-2.44
15	309.00	310.52	-1.52	-0.49
16	304.00	300.90	3.10	1.02
17	298.00	291.44	6.56	2.20
18	290.00	282.61	7.39	2.55
19	284.00	275.13	8.87	3.12
20	278.00	268.39	9.61	3.46
21	270.00	262.32	7.68	2.84
22	263.00	256.74	6.26	2.38
23	256.00	251.58	4.42	1.73
24	250.00	246.26	3.74	1.50
25	245.00	241.56	3.44	1.40
26	239.00	237.04	1.96	0.82
27	235.00	232.86	2.14	0.91
28	232.00	228.99	3.01	1.30
29	228.00	225.52	2.48	1.09
30	224.00	222.19	1.81	0.81
31	221.00	219.05	1.95	0.88
32	218.00	216.05	1.95	0.89
33	216.00	213.68	2.32	1.07
34	214.00	211.47	2.53	1.18
35	211.00	209.41	1.59	0.75
36	209.00	207.28	1.72	0.82
37	206.00	205.02	0.98	0.48
38	203.00	202.85	0.15	0.08
39	200.00	200.73	-0.73	-0.37
40	198.00	199.00	-1.00	-0.51

THE EQUATION FOR THIS MODEL IS: THAT = B0 * X1 ** B1
IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1)
WHERE: LOG(B0) = 3.49572 STD ERROR = 0.13455 B0 = 3131.24004
B1 =-0.28262 STD ERROR = 0.00433

SUMMARY STATISTICS:

R SQUARED LOG =0.99115 STD ERROR EST = 0.0164
MSE = 0.00027 MSR = 1.14390
F RATIO =4255.4805 D. F. (N/D) = 1/ 38
R SQUARED ACTUAL=0.98061 LEARNING FACTOR = 82.20945 PERCENT
DURBIN-WATSON STATISTIC= 0.327753

RESULTS OF REGRESSION ON PRODUCTION RATE VARIABLE ALONE

CASE	OBSERVED	PREDICTED	RESIDUAL	% DEVIATION
1	1088.00	974.84	113.16	10.40
2	803.00	656.04	144.96	18.05
3	641.00	590.83	50.17	7.83
4	560.00	546.65	13.35	2.38
5	493.00	516.61	-23.61	-4.79
6	462.00	482.04	-20.04	-4.34
7	437.00	447.24	-10.24	-2.34
8	404.00	435.28	-31.28	-7.74
9	368.00	421.80	-53.80	-14.62
10	347.00	405.94	-58.94	-16.99
11	330.00	389.54	-59.54	-18.04
12	320.00	370.60	-50.60	-15.81
13	317.00	347.29	-30.29	-9.56
14	313.00	326.90	-13.90	-4.44
15	309.00	311.74	-2.74	-0.89
16	304.00	297.93	6.07	2.00
17	298.00	286.02	11.98	4.02
18	290.00	276.15	13.85	4.77
19	284.00	268.13	15.87	5.59
20	278.00	260.49	17.51	6.30
21	270.00	256.65	13.35	4.95
22	263.00	252.13	10.87	4.13
23	256.00	248.82	7.18	2.80
24	250.00	243.50	6.50	2.60
25	245.00	239.50	5.50	2.25
26	239.00	235.87	3.13	1.31
27	235.00	231.83	3.17	1.35
28	232.00	227.62	4.38	1.89
29	228.00	224.40	3.60	1.58
30	224.00	221.29	2.71	1.21
31	221.00	218.27	2.73	1.23
32	218.00	215.45	2.55	1.17
33	216.00	212.79	3.21	1.48
34	214.00	210.57	3.43	1.60
35	211.00	208.83	2.17	1.03
36	209.00	207.03	1.97	0.94
37	206.00	205.44	0.56	0.27
38	203.00	204.04	-1.04	-0.51
39	200.00	202.42	-2.42	-1.21
40	198.00	201.15	-3.15	-1.59

THE EQUATION FOR THIS MODEL IS: YHAT = B0 * X2 ** B2

IN LOG FORM THIS MODEL BECOMES: LOG(YHAT) = LOG(B0) + B2 * LOG(X2)

WHERE: LOG(B0) = 3.25379 STD ERROR = 0.23957 B0 = 1793.86990

B2 =-0.74392 STD ERROR = 0.02175

SUMMARY STATISTICS:

R SQUARED LOG	=0.96854	STD ERROR EST =	0.0389
MSE	= 0.00096	MSR	= 1.11780
F RATIO	=1169.7950	D. F. (N/D)	= 1/ 38

R SQUARED ACTUAL=0.95679

DURBIN-WATSON STATISTIC= 0.277265

RESULTS OF COMBINED CUMULATIVE PRODUCTION AND PRODUCTION RATE MODEL

CASE	OBSERVED	PREDICTED	RESIDUAL	% DEVIATION
1	1088.00	1088.13	-0.13	-0.01
2	893.00	893.15	-0.15	-0.02
3	641.00	640.73	0.27	0.04
4	560.00	560.09	-0.09	-0.02
5	493.00	492.67	0.33	0.07
6	462.00	461.92	0.08	0.02
7	437.00	437.10	-0.10	-0.02
8	404.00	404.12	-0.12	-0.03
9	366.00	366.24	-0.24	-0.07
10	347.00	347.04	-0.04	-0.01
11	330.00	329.59	0.41	0.12
12	320.00	319.59	0.41	0.13
13	317.00	317.50	-0.50	-0.16
14	313.00	313.28	-0.28	-0.09
15	309.00	308.97	0.03	0.01
16	304.00	304.32	-0.32	-0.10
17	298.00	297.89	0.11	0.04
18	290.00	290.45	-0.45	-0.15
19	284.00	283.75	0.25	0.09
20	278.00	278.21	-0.21	-0.07
21	270.00	269.56	0.44	0.16
22	263.00	262.80	0.20	0.08
23	256.00	255.53	0.47	0.18
24	250.00	250.29	-0.29	-0.11
25	245.00	244.84	0.16	0.07
26	239.00	239.34	-0.34	-0.14
27	235.00	235.07	-0.07	-0.03
28	232.00	231.63	0.37	0.16
29	228.00	227.91	0.09	0.04
30	224.00	224.38	-0.38	-0.17
31	221.00	221.13	-0.13	-0.06
32	218.00	217.97	0.03	0.02
33	216.00	215.95	0.05	0.02
34	214.00	213.78	0.22	0.10
35	211.00	211.38	-0.38	-0.18
36	209.00	208.88	0.12	0.06
37	206.00	205.88	0.12	0.06
38	203.00	202.85	0.15	0.07
39	200.00	200.20	-0.20	-0.10
40	198.00	197.97	0.03	0.01

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THE EQUATION FOR THIS MODEL IS:      THAT = B0 * X1 ** B1 * X2 **B2
IN LOG FORM THIS MODEL BECOMES: LOG(THAT) = LOG(B0) + B1 * LOG(X1) + B2 * LOG(X2)
WHERE: LOG(B0) = 3.75380   STD ERROR = 0.00116   B0 = 5672.84668
           B1 =-0.59957   STD ERROR = 0.00134   F= =00532.2109
           B2 = 0.04696   STD ERROR = 0.00356   F= =56304.9604
SUMMARY STATISTICS:
R SQUARED LOG   =0.99999          STD ERROR EST =     0.0004
MSE             =  0.00000        MSR           =  0.57705
F RATIO         =7908.2812        D. F. (N/D)   = 2/ 37
R SQUARED ACTUAL=1.00000
DURBIN-WATSON STATISTIC= 2.300320
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SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 40 WHICH HAS AN OBSERVED VALUE OF: 198.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
39	199.06	-0.53	3129.81	-0.28252	197.97	0.02	5673.27	-0.59961	0.84784
38	199.10	-0.56	3127.20	-0.28244	197.98	0.01	5671.21	-0.59947	0.84673
37	199.10	-0.56	3127.32	-0.28244	197.97	0.01	5671.58	-0.59947	0.84669
36	199.05	-0.53	3129.39	-0.28254	197.97	0.02	5671.34	-0.59941	0.84649
35	198.94	-0.47	3133.42	-0.28273	197.96	0.02	5671.37	-0.59938	0.84637
34	198.83	-0.42	3137.51	-0.28292	197.98	0.01	5671.01	-0.59945	0.84669
33	198.64	-0.32	3144.39	-0.28324	197.97	0.02	5671.22	-0.59941	0.84656
32	198.45	-0.22	3151.43	-0.28357	197.96	0.02	5671.03	-0.59937	0.84639
31	198.25	-0.13	3158.24	-0.28389	197.96	0.02	5671.17	-0.59937	0.84637
30	198.04	-0.02	3165.76	-0.28424	197.97	0.02	5670.86	-0.59938	0.84643
29	197.81	0.09	3173.66	-0.28462	198.00	-0.00	5669.98	-0.59943	0.84671
28	197.50	0.25	3184.44	-0.28513	198.00	0.00	5670.05	-0.59941	0.84664

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 39 WHICH HAS AN OBSERVED VALUE OF: 200.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
38	200.83	-0.42	3127.20	-0.28244	200.21	-0.10	5671.21	-0.59947	0.84673
37	200.83	-0.42	3127.32	-0.28244	200.20	-0.10	5671.58	-0.59947	0.84669
36	200.78	-0.39	3129.39	-0.28254	200.19	-0.10	5671.34	-0.59941	0.84649
35	200.67	-0.33	3133.42	-0.28273	200.18	-0.09	5671.37	-0.59938	0.84637
34	200.56	-0.28	3137.51	-0.28292	200.21	-0.10	5671.01	-0.59945	0.84669
33	200.37	-0.19	3144.39	-0.28324	200.19	-0.10	5671.22	-0.59941	0.84650
32	200.18	-0.09	3151.43	-0.28357	200.19	-0.09	5671.03	-0.59937	0.84639
31	199.99	0.01	3158.24	-0.28389	200.19	-0.09	5671.17	-0.59937	0.84637
30	199.77	0.11	3165.76	-0.28424	200.20	-0.10	5670.86	-0.59938	0.84643
29	199.55	0.23	3173.66	-0.28462	200.23	-0.11	5669.98	-0.59943	0.84671
28	199.23	0.39	3184.44	-0.28513	200.22	-0.11	5670.05	-0.59941	0.84664
27	198.83	0.59	3198.10	-0.28578	200.19	-0.09	5670.15	-0.59933	0.84619

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 38 WHICH HAS AN OBSERVED VALUE OF: 203.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
37	202.94	0.03	3127.32	-0.28244	202.85	0.07	5671.58	-0.59947	0.84669
36	202.89	0.05	3129.39	-0.28254	202.84	0.08	5671.34	-0.59941	0.84649
35	202.78	0.11	3133.42	-0.28273	202.83	0.08	5671.37	-0.59938	0.84637
34	202.67	0.16	3137.51	-0.28292	202.86	0.07	5671.01	-0.59945	0.84669
33	202.49	0.25	3144.39	-0.28324	202.84	0.08	5671.22	-0.59941	0.84650
32	202.29	0.35	3151.43	-0.28357	202.84	0.08	5671.03	-0.59937	0.84639
31	202.10	0.44	3158.24	-0.28389	202.84	0.08	5671.17	-0.59937	0.84637
30	201.89	0.55	3165.76	-0.28424	202.85	0.08	5670.06	-0.59938	0.84643
29	201.66	0.66	3173.66	-0.28462	202.88	0.06	5669.98	-0.59943	0.84671
28	201.35	0.81	3184.44	-0.28513	202.87	0.06	5670.05	-0.59941	0.84664
27	200.94	1.01	3198.10	-0.28578	202.84	0.08	5670.15	-0.59938	0.84619
26	200.57	1.20	3210.66	-0.28630	202.85	0.08	5669.98	-0.59938	0.84623

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 37 WHICH HAS AN OBSERVED VALUE OF: 206.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
36	205.66	0.45	3129.39	-0.28254	205.87	0.06	5671.34	-0.59941	0.84649
35	204.96	0.51	3133.42	-0.28273	205.86	0.07	5671.37	-0.59938	0.84637
34	204.85	0.56	3137.51	-0.28292	205.89	0.05	5671.01	-0.59945	0.84669
33	204.66	0.65	3144.39	-0.28324	205.87	0.06	5671.22	-0.59941	0.84650
32	204.47	0.74	3151.43	-0.28357	205.87	0.06	5671.03	-0.59937	0.84639
31	204.28	0.84	3158.24	-0.28389	205.87	0.06	5671.17	-0.59937	0.84637
30	204.07	0.94	3165.76	-0.28424	205.88	0.06	5670.06	-0.59938	0.84643
29	203.84	1.05	3173.66	-0.28462	205.91	0.04	5669.98	-0.59943	0.84671
28	203.53	1.20	3184.44	-0.28513	205.90	0.05	5670.05	-0.59941	0.84664
27	203.12	1.40	3198.10	-0.28578	205.87	0.06	5670.15	-0.59938	0.84619
26	202.75	1.58	3210.66	-0.28630	205.88	0.05	5669.98	-0.59938	0.84623
25	202.33	1.78	3224.20	-0.28702	205.91	0.04	5669.57	-0.59940	0.84663

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 36 WHICH HAS AN OBSERVED VALUE OF: 209.00

# CASES	REDUCED (LEARNING CURVE) MODEL				FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL				
USED	PREDICTION	% DEVIATION	EST B0	EST B1	PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
35	207.22	0.85	3133.42	-0.28273	208.86	0.06	5671.37	-0.59938	0.84637
34	207.11	0.91	3137.51	-0.28292	208.89	0.05	5671.01	-0.59945	0.84669
33	206.92	0.99	3144.39	-0.28324	208.87	0.06	5671.22	-0.59941	0.84650
32	206.73	1.09	3151.43	-0.28357	208.87	0.06	5671.03	-0.59937	0.84639
31	206.54	1.18	3158.24	-0.28389	208.87	0.06	5671.17	-0.59937	0.84637
30	206.33	1.28	3165.76	-0.28424	208.88	0.06	5670.86	-0.59938	0.84643
29	206.10	1.39	3173.66	-0.28462	208.91	0.04	5669.98	-0.59943	0.84671
28	205.79	1.54	3184.44	-0.28513	208.90	0.05	5670.05	-0.59941	0.84664
27	205.39	1.73	3198.10	-0.28578	208.87	0.06	5670.15	-0.59938	0.84619
26	205.01	1.91	3210.66	-0.28630	208.88	0.06	5669.98	-0.59938	0.84623
25	204.60	2.11	3224.20	-0.28702	208.91	0.04	5669.57	-0.59948	0.84663
24	203.98	2.40	3244.48	-0.28799	208.90	0.05	5669.29	-0.59932	0.84635

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 35 WHICH HAS AN OBSERVED VALUE OF: 211.00

# CASES	REDUCED (LEARNING CURVE) MODEL				FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL				
USED	PREDICTION	% DEVIATION	EST B0	EST B1	PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
34	209.24	0.83	3137.51	-0.28292	211.39	-0.19	5671.01	-0.59945	0.84669
33	209.06	0.92	3144.39	-0.28324	211.38	-0.18	5671.22	-0.59941	0.84650
32	208.86	1.01	3151.43	-0.28357	211.37	-0.18	5671.03	-0.59937	0.84639
31	208.67	1.10	3158.24	-0.28389	211.37	-0.17	5671.17	-0.59937	0.84637
30	208.46	1.20	3165.76	-0.28424	211.38	-0.18	5670.86	-0.59938	0.84643
29	208.24	1.31	3173.66	-0.28462	211.41	-0.19	5669.98	-0.59943	0.84671
28	207.93	1.46	3184.44	-0.28513	211.40	-0.19	5670.05	-0.59941	0.84664
27	207.52	1.65	3198.10	-0.28578	211.37	-0.18	5670.15	-0.59938	0.84619
26	207.15	1.82	3210.66	-0.28630	211.38	-0.18	5669.98	-0.59938	0.84623
25	206.74	2.02	3224.20	-0.28702	211.41	-0.20	5669.57	-0.59948	0.84663
24	206.12	2.31	3244.46	-0.28799	211.40	-0.19	5669.29	-0.59932	0.84635
23	205.37	2.67	3268.45	-0.28914	211.43	-0.21	5669.31	-0.59947	0.84698

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 34 WHICH HAS AN OBSERVED VALUE OF: 214.00

# CASES	REDUCED (LEARNING CURVE) MODEL				FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL				
USED	PREDICTION	% DEVIATION	EST B0	EST B1	PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
33	211.12	1.35	3144.39	-0.28324	213.78	0.10	5671.22	-0.59941	0.84656
32	210.92	1.44	3151.43	-0.28357	213.78	0.11	5671.03	-0.59937	0.84639
31	210.74	1.53	3158.24	-0.28389	213.77	0.11	5671.17	-0.59937	0.84637
30	210.53	1.62	3165.76	-0.28424	213.78	0.10	5670.86	-0.59938	0.84643
29	210.30	1.73	3173.66	-0.28462	213.81	0.09	5669.98	-0.59943	0.84671
28	209.99	1.87	3184.44	-0.28513	213.81	0.09	5670.05	-0.59941	0.84664
27	209.59	2.06	3196.10	-0.28578	213.77	0.11	5670.15	-0.59938	0.84619
26	209.21	2.24	3210.66	-0.28638	213.78	0.10	5669.98	-0.59938	0.84623
25	208.83	2.43	3224.20	-0.28702	213.82	0.09	5669.57	-0.59940	0.84663
24	208.18	2.72	3244.40	-0.28799	213.80	0.09	5669.29	-0.59932	0.84635
23	207.43	3.07	3268.45	-0.28914	213.84	0.08	5669.51	-0.59947	0.84690
22	206.49	3.51	3298.29	-0.29058	213.78	0.10	5668.70	-0.59920	0.84597

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 33 WHICH HAS AN OBSERVED VALUE OF: 216.00

# CASES	REDUCED (LEARNING CURVE) MODEL				FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL				
USED	PREDICTION	% DEVIATION	EST B0	EST B1	PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
32	213.14	1.33	3151.43	-0.28357	215.94	0.03	5671.03	-0.59937	0.84639
31	212.95	1.41	3158.24	-0.28389	215.94	0.03	5671.17	-0.59937	0.84637
30	212.74	1.51	3165.76	-0.28424	215.95	0.03	5670.86	-0.59938	0.84643
29	212.51	1.61	3173.66	-0.28462	215.98	0.01	5669.98	-0.59943	0.84671
28	212.28	1.76	3184.44	-0.28513	215.97	0.01	5670.05	-0.59941	0.84664
27	211.88	1.94	3196.10	-0.28578	215.94	0.03	5670.15	-0.59938	0.84619
26	211.43	2.12	3210.66	-0.28638	215.94	0.03	5669.98	-0.59938	0.84623
25	211.02	2.31	3224.20	-0.28702	215.98	0.01	5669.57	-0.59940	0.84663
24	210.40	2.59	3244.40	-0.28799	215.96	0.02	5669.29	-0.59932	0.84635
23	209.65	2.94	3268.45	-0.28914	216.00	-0.00	5669.51	-0.59947	0.84690
22	208.71	3.38	3298.29	-0.29058	215.95	0.03	5668.70	-0.59920	0.84597
21	207.39	3.99	3339.76	-0.29256	215.91	0.04	5667.92	-0.59902	0.84537

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 32 WHICH HAS AN OBSERVED VALUE OF: 218.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
31	215.32	1.23	3158.24	-0.28389	217.95	0.02	5671.17	-0.59937	0.84637
30	215.11	1.33	3165.76	-0.28424	217.96	0.02	5670.86	-0.59936	0.84643
29	214.89	1.43	3173.66	-0.28462	218.00	0.00	5669.98	-0.59943	0.84671
28	214.58	1.57	3184.44	-0.28513	217.99	0.00	5670.05	-0.59941	0.84664
27	214.18	1.75	3198.10	-0.28578	217.96	0.02	5670.15	-0.59938	0.84619
26	213.81	1.92	3210.66	-0.28638	217.96	0.02	5669.98	-0.59938	0.84623
25	213.40	2.11	3224.20	-0.28702	218.00	0.00	5669.57	-0.59948	0.84663
24	212.78	2.40	3244.40	-0.28799	217.98	0.01	5669.29	-0.59932	0.84635
23	212.03	2.74	3268.45	-0.28914	218.02	-0.01	5669.51	-0.59947	0.84690
22	211.09	3.17	3298.29	-0.29058	217.96	0.02	5668.70	-0.59920	0.84597
21	209.77	3.78	3339.76	-0.29256	217.93	0.03	5667.92	-0.59982	0.84537
20	208.04	4.57	3393.89	-0.29513	217.84	0.07	5664.33	-0.59840	0.84339

SHORTRANGE PREDICTIVE ABILITY COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 31 WHICH HAS AN OBSERVED VALUE OF: 221.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
30	218.11	1.31	3165.76	-0.28424	221.12	-0.06	5670.86	-0.59936	0.84643
29	217.89	1.41	3173.66	-0.28462	221.16	-0.07	5669.98	-0.59943	0.84671
28	217.58	1.55	3184.44	-0.28513	221.15	-0.07	5670.05	-0.59941	0.84664
27	217.18	1.73	3198.10	-0.28578	221.12	-0.05	5670.15	-0.59938	0.84619
26	216.81	1.90	3210.66	-0.28638	221.12	-0.06	5669.98	-0.59939	0.84623
25	216.40	2.08	3224.20	-0.28702	221.16	-0.07	5669.57	-0.59940	0.84663
24	215.79	2.36	3244.40	-0.28799	221.14	-0.06	5669.29	-0.59932	0.84635
23	215.04	2.70	3268.45	-0.28914	221.18	-0.08	5669.51	-0.59947	0.84690
22	214.10	3.12	3298.29	-0.29058	221.12	-0.06	5668.70	-0.59920	0.84597
21	212.78	3.72	3339.76	-0.29256	221.09	-0.04	5667.92	-0.59982	0.84537
20	211.06	4.50	3393.89	-0.29513	221.00	-0.00	5664.33	-0.59840	0.84339
19	208.76	5.54	3466.08	-0.29853	221.02	-0.01	5664.84	-0.59849	0.84366

SHORTRANGE PREDICTIVE ABILITI COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 30 WHICH HAS AN OBSERVED VALUE OF: 224.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL				FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL				
	PREDICTION	% DEVIATION	EST B0	EST B1	PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
29	221.04	1.32	3173.66	-0.28462	224.41	-0.18	5669.98	-0.59943	0.84671
28	220.73	1.46	3184.44	-0.28513	224.40	-0.18	5670.05	-0.59941	0.84664
27	220.33	1.64	3198.10	-0.28570	224.37	-0.17	5670.15	-0.59938	0.84619
26	219.96	1.80	3210.66	-0.28638	224.38	-0.17	5669.98	-0.59938	0.84623
25	219.56	1.98	3224.20	-0.28702	224.41	-0.18	5669.57	-0.59940	0.84663
24	218.94	2.26	3244.40	-0.28799	224.40	-0.18	5669.29	-0.59932	0.84635
23	218.20	2.59	3268.45	-0.28914	224.43	-0.19	5669.51	-0.59947	0.84690
22	217.26	3.01	3298.29	-0.29058	224.38	-0.17	5668.70	-0.59920	0.84597
21	215.94	3.60	3339.76	-0.29256	224.34	-0.15	5667.92	-0.59902	0.84537
20	214.22	4.37	3393.89	-0.29513	224.26	-0.12	5664.33	-0.59840	0.84339
19	211.92	5.39	3466.08	-0.29853	224.27	-0.12	5664.04	-0.59849	0.84366
18	209.29	6.57	3549.33	-0.30240	224.17	-0.08	5660.02	-0.59772	0.84127

SHORTRANGE PREDICTIVE ABILITI COMPARISON

THE DATA PRESENTED BELOW IS FOR CASE # 29 WHICH HAS AN OBSERVED VALUE OF: 228.00

# CASES USED	REDUCED (LEARNING CURVE) MODEL				FULL (CUMULATIVE PRODUCTION & PRODUCTION RATE) MODEL				
	PREDICTION	% DEVIATION	EST B0	EST B1	PREDICTION	% DEVIATION	EST B0	EST B1	EST B2
28	224.06	1.73	3184.44	-0.28513	227.93	0.03	5670.05	-0.59941	0.84664
27	223.67	1.90	3198.10	-0.28570	227.90	0.05	5670.15	-0.59938	0.84619
26	223.30	2.06	3210.66	-0.28638	227.90	0.04	5669.98	-0.59938	0.84623
25	222.89	2.24	3224.20	-0.28702	227.94	0.03	5669.57	-0.59940	0.84663
24	222.28	2.51	3244.40	-0.28799	227.92	0.03	5669.29	-0.59932	0.84635
23	221.54	2.84	3268.45	-0.28914	227.96	0.02	5669.51	-0.59947	0.84690
22	220.60	3.25	3298.29	-0.29058	227.90	0.04	5668.70	-0.59920	0.84597
21	219.29	3.82	3339.76	-0.29256	227.87	0.06	5667.92	-0.59902	0.84537
20	217.57	4.58	3393.89	-0.29513	227.78	0.10	5664.33	-0.59840	0.84339
19	215.27	5.58	3466.08	-0.29853	227.79	0.09	5664.04	-0.59849	0.84366
18	212.64	6.74	3549.33	-0.30240	227.69	0.13	5660.02	-0.59772	0.84127
17	209.70	8.03	3642.99	-0.30670	227.76	0.10	5663.39	-0.59825	0.84293

SUMMARY OF PREDICTIVE ABILITY TESTS RESULTS

ITEMS OF INTEREST	REDUCED MODEL	FULL MODEL
AVERAGE ABSOLUTE DEVIATION	3.04	0.16
VARIANCE OF ABSOLUTE DEVIATIONS	10.66	0.01
TEST STATISTIC (SEE NOTE)	---	13.50
TOTAL NUMBER OF TEST SITUATIONS	144	144
NUMBER OF PREDICTIONS WITHIN 5%	138	144
PERCENT OF PREDICTIONS WITHIN 5%	95.	100.
NUMBER OF PREDICTIONS WITHIN 10%	144	144
PERCENT OF PREDICTIONS WITHIN 10%	100.	100.

NOTE: IN TESTING FOR STATISTICAL SIGNIFICANCE USE STUDENT'S T DISTRIBUTION IF THE NUMBER OF TEST SITUATIONS ARE LESS THAN 60; OTHERWISE USE STANDARD NORMAL DISTRIBUTION. IN EITHER CASE THIS IS A ONE TAILED TEST. IF THE TEST STATISTIC IS GREATER THAN THE CRITICAL STATISTIC ONE MAY CONCLUDE THAT THE AVERAGE ABSOLUTE DEVIATION OBTAINED WITH THE FULL MODEL IS SIGNIFICANTLY LESS THAN THAT OBTAINED WITH THE REDUCED MODEL.

FILES LOGFILE,STDLEARN,REDHOURS,AND FULLMODL WRITTEN.

PROJECTION AND SENSITIVITY MATRIX

PROJECTED CUMULATIVE UNITS	PROJECTED PRODUCTION RATES								
	13.26	15.15	17.05	18.94	20.83	22.73	24.62	26.52	28.41
25929	114.3	128.0	141.4	154.6	167.6	180.5	193.1	205.6	218.0
26101	113.9	127.5	140.9	154.0	167.0	179.7	192.3	204.8	217.1
26273	113.4	127.0	140.3	153.4	166.3	179.0	191.6	204.0	216.3
26444	113.0	126.5	139.8	152.8	165.7	178.3	190.8	203.2	215.4
26616	112.5	126.0	139.2	152.2	165.0	177.6	190.1	202.4	214.6
26788	112.1	125.5	138.7	151.6	164.4	177.0	189.4	201.6	213.8
26960	111.7	125.0	138.2	151.1	163.8	176.3	188.6	200.9	213.0
27131	111.3	124.6	137.6	150.5	163.1	175.6	187.9	200.1	212.N
27303	110.8	124.1	137.1	149.9	162.5	175.0	187.2	199.4	211.3
27475	110.4	123.6	136.6	149.4	161.9	174.3	186.5	198.6	210.6
27646	110.0	123.2	136.1	148.8	161.3	173.6	185.8	197.9	209.8
27818	109.6	122.7	135.6	148.2	160.7	173.0	185.1	197.1	209.0
27990	109.2	122.3	135.1	147.7	160.1	172.4	184.5	196.4	208.2
28162	108.8	121.8	134.6	147.2	159.5	171.7	183.8	195.7	207.5
28333	108.4	121.4	134.1	146.6	159.0	171.1	183.1	195.0	206.N
28505	108.0	120.9	133.6	146.1	158.4	170.5	182.4	194.3	206.0
28677	107.6	120.5	133.1	145.6	157.8	169.9	181.8	193.6	205.2
28848	107.2	120.1	132.7	145.1	157.2	169.3	181.1	192.9	204.5
29020	106.9	119.6	132.2	144.5	156.7	168.7	180.5	192.2	203.8
29192	106.5	119.2	131.7	144.0	156.1	168.1	179.9	191.5	203.0
29364	106.1	118.8	131.3	143.5	155.6	167.5	179.2	190.8	202.3
29535	105.7	118.4	130.8	143.0	155.0	166.9	178.6	190.2	201.6
29707	105.4	118.0	130.4	142.5	154.5	166.3	178.0	189.5	200.9
29879	105.0	117.6	129.9	142.0	154.0	165.7	177.4	188.9	200.2
30050	104.6	117.2	129.5	141.5	153.4	165.2	176.8	188.2	199.5
30222	104.3	116.8	129.0	141.1	152.9	164.6	176.2	187.6	198.9
30394	103.9	116.4	128.6	140.6	152.4	164.1	175.6	186.9	198.2
30566	103.6	116.0	128.1	140.1	151.9	163.5	175.0	186.3	197.5
30737	103.2	115.6	127.7	139.6	151.4	163.0	174.4	185.7	196.9
30909	102.9	115.2	127.3	139.2	150.9	162.4	173.8	185.1	196.2
31081	102.5	114.8	126.9	138.7	150.4	161.9	173.2	184.4	195.5
31253	102.2	114.4	126.4	138.3	149.9	161.3	172.7	183.8	194.9
31424	101.9	114.1	126.0	137.8	149.4	160.8	172.1	183.2	194.3
31596	101.5	113.7	125.6	137.3	148.9	160.3	171.5	182.6	193.6
31768	101.2	113.3	125.2	136.9	148.4	159.8	171.0	182.0	193.0
31939	100.9	113.0	124.8	136.5	147.9	159.3	170.4	181.5	192.4
32111	100.6	112.6	124.4	136.0	147.5	158.7	169.9	180.9	191.8
32283	100.2	112.2	124.0	135.6	147.0	158.2	169.3	180.3	191.1
32455	99.9	111.9	123.6	135.2	146.5	157.7	168.8	179.7	190.5
32626	99.6	111.5	123.2	134.7	146.1	157.2	168.3	179.2	189.9
32798	99.3	111.2	122.8	134.3	145.6	156.7	167.7	178.6	189.3
32970	99.0	110.8	122.5	133.9	145.1	156.2	167.2	178.0	188.7
33141	98.7	110.5	122.1	133.5	144.7	155.8	166.7	177.5	188.2
33313	98.4	110.1	121.7	133.1	144.2	155.3	166.2	176.9	187.6
33485	98.1	109.8	121.3	132.7	143.8	154.8	165.7	176.4	187.0
33657	97.8	109.5	121.0	132.2	143.4	154.3	165.2	175.8	186.4
33828	97.5	109.1	120.6	131.8	142.9	153.9	164.6	175.3	185.9
34000	97.2	108.8	120.2	131.4	142.5	153.4	164.1	174.8	185.3
34172	96.9	108.5	119.9	131.0	142.1	152.9	163.7	174.3	184.7
34343	96.6	108.2	119.5	130.7	141.6	152.5	163.2	173.7	184.2

NOTE: 1. PROJECTED VALUES FOR DIRECT LABOR HOURS MAY BE READ FROM THE ABOVE MATRIX BY MATCHING A GIVEN PRODUCTION RATE WITH A GIVEN NUMBER OF CUMULATIVE UNITS AND READING THE VALUE FOR DIRECT LABOR HOURS FOUND AT THE INTERSECTION OF THE CORRESPONDING ROW AND COLUMN. FORECASTING MODEL IS THE CUMULATIVE PRODUCTION & PRODUCTION RATE MODEL.

2. PROJECTION INTERVAL FOR CUMULATIVE UNITS IS 1% OF THE LAST OBSERVED VALUE OF CUMULATIVE UNITS.

3. PROJECTION VALUES FOR PRODUCTION RATE ARE 70, 80, 90, 100, 110, 120, 130, 140, AND 150 PERCENT OF THE LAST OBSERVED VALUE OF PRODUCTION RATE.

PROJECTION AND SENSITIVITY MATRIX

PROJECTED CUMULATIVE UNITS	PROJECTED PRODUCTION RATES								
	13.26	15.15	17.05	18.94	20.83	22.73	24.62	26.52	28.41
17343	145.5	162.9	180.0	196.8	213.3	229.7	245.8	261.7	277.4
17515	144.6	161.9	178.9	195.6	212.1	228.3	244.3	260.1	275.8
17687	143.8	161.0	177.9	194.5	210.8	227.0	242.9	258.6	274.2
17858	143.0	160.1	176.9	193.4	209.6	225.7	241.5	257.1	272.6
18030	142.1	159.2	175.9	192.3	208.4	224.4	240.1	255.7	271.0
18202	141.3	158.3	174.9	191.2	207.2	223.1	238.7	254.2	269.5
18374	140.5	157.4	173.9	190.1	206.1	221.8	237.4	252.8	268.0
18545	139.8	156.5	172.9	189.0	204.9	220.6	236.1	251.4	266.5
18717	139.0	155.6	172.0	188.0	203.8	219.4	234.8	250.0	265.0
18889	138.2	154.8	171.0	187.0	202.7	218.2	233.5	248.6	263.6
19060	137.5	153.9	170.1	186.0	201.6	217.0	232.2	247.3	262.2
19232	136.7	153.1	169.2	185.0	200.5	215.9	231.0	246.0	260.8
19404	136.0	152.3	168.3	184.0	199.5	214.7	229.8	244.7	259.4
19576	135.3	151.5	167.4	183.0	198.4	213.6	228.6	243.4	258.0
19747	134.6	150.7	166.5	182.1	197.4	212.5	227.4	242.1	256.7
19919	133.9	149.9	165.7	181.1	196.3	211.4	226.2	240.8	255.3
20091	133.2	149.2	164.8	180.2	195.3	210.3	225.0	239.6	254.0
20262	132.5	148.4	164.0	179.3	194.3	209.2	223.9	238.4	252.7
20434	131.9	147.7	163.1	178.4	193.4	208.2	222.8	237.2	251.5
20606	131.2	146.9	162.3	177.5	192.4	207.1	221.6	236.0	250.2
20778	130.5	146.2	161.5	176.6	191.4	206.1	220.5	234.8	248.9
20949	129.9	145.5	160.7	175.7	190.5	205.1	219.5	233.7	247.7
21121	129.3	144.8	159.9	174.9	189.6	204.1	218.4	232.5	246.5
21293	128.6	144.0	159.2	174.0	188.6	203.1	217.3	231.4	245.3
21464	128.0	143.4	158.4	173.2	187.7	202.1	216.3	230.3	244.1
21636	127.4	142.7	157.6	172.4	186.8	201.1	215.2	229.2	243.0
21808	126.8	142.0	156.9	171.5	186.0	200.2	214.2	228.1	241.8
21980	126.2	141.3	156.2	170.7	185.1	199.2	213.2	227.0	240.7
22151	125.6	140.7	155.4	169.9	184.2	198.3	212.2	226.0	239.6
22323	125.1	140.0	154.7	169.2	183.4	197.4	211.2	224.9	238.5
22495	124.5	139.4	154.0	168.4	182.5	196.5	210.3	223.9	237.4
22667	123.9	138.7	153.3	167.6	181.7	195.6	209.3	222.9	236.3
22838	123.4	138.1	152.6	166.9	180.9	194.7	208.4	221.9	235.2
23010	122.8	137.5	151.9	166.1	180.1	193.8	207.4	220.9	234.2
23182	122.3	136.9	151.3	165.4	179.3	193.0	206.5	219.9	233.1
23353	121.7	136.3	150.6	164.6	178.5	192.1	205.6	218.9	232.1
23525	121.2	135.7	149.9	163.9	177.7	191.3	204.7	218.0	231.1
23697	120.7	135.1	149.3	163.2	176.9	190.5	203.8	217.0	230.1
23869	120.2	134.5	148.6	162.5	176.2	189.6	202.9	216.1	229.1
24040	119.6	133.9	148.0	161.8	175.4	188.8	202.1	215.2	228.1
24212	119.1	133.4	147.4	161.1	174.7	188.0	201.2	214.2	227.1
24384	118.6	132.8	146.7	160.4	173.9	187.2	200.4	213.3	226.2
24555	118.1	132.3	146.1	159.8	173.2	186.4	199.5	212.4	225.2
24727	117.6	131.7	145.5	159.1	172.5	185.7	198.7	211.6	224.3
24899	117.1	131.2	144.9	158.4	171.8	184.9	197.9	210.7	223.4
25071	116.6	130.6	144.3	157.8	171.0	184.1	197.0	209.8	222.4
25242	116.2	130.1	143.7	157.1	170.4	183.4	196.2	209.0	221.5
25414	115.7	129.6	143.1	156.5	169.7	182.6	195.4	208.1	220.6
25586	115.2	129.0	142.6	155.9	169.0	181.9	194.7	207.3	219.7
25757	114.8	128.5	142.0	155.3	168.3	181.2	193.9	206.4	218.9

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